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RENDICONTI DEL CONGRESSO INTERNAZIONALE
SULLE PARTICELLE INSTABILI PESANTI E SUGLI EVENTI DI ALTA ENERGIA NEI RAGGI COSMICI

TENUTOSI A PADOVA NEI GIORNI 12-15 APRILE 1954

INDICE

SEZIONE I

Introduzione.

PREFAZIONE

A. ROSTAGNI

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

L'idea di questo Congresso fu avanzata tra i partecipanti alla spedizione di Sardegna compiuta nell'estate 1953, per ricerche sul a radiazione cosmica in alta atmosfera, quando essi si riunirono, ai primi di Ottobre dell'anno scorso, a Berna per la ripartizione delle lastre. Dato che nella spedizione si era fatto uso principalmente della nuova tecnica della emulsioni libere (stripped), si pensò che potesse valere la pena di incontrarsi di nuovo dopo pochi mesi per porre a confronto i primi risultati e trarne eventuali conclusioni e, soprattutto, indicazioni utili ad una migliore organizzazione delle ricerche ulteriori.

Nella sua traduzione in atto questo progetto si è alquanto ampliato. In primo luogo, il materiale raccolto in sei mesi di studio delle emulsioni, è risultato assai più abbondante di quanto non si potesse a priori prevedere. D'altro lato è sembrato opportuno, direi quasi indispensabile per la discussione delle nostre osservazioni colle emulsioni, avere a disposizione i risultati delle esperienze colle camere di Wilson, e di quelle con emulsioni esposte a grandi altezze compiute da altri laboratori, non partecipanti alla spedizione, come i laboratori indiani ed americani, che così larga messe di risultati avevano recato al Congresso di Bagnères-de-Bigorre del Luglio 1953. Perciò venne estesa alquanto la cerchia degli inviti. Alcuni poi fra gli invitati che non poterono intervenire, hanno tuttavia inviato le loro comunicazioni, le qua i sono state riassunte al Congresso e incluse in questo fascicolo, contribuendo in questo modo, senza dubbio, ad accrescerne l'interesse e l'importanza.

Cosí si potè redigere un quadro abbastanza completo dello stato attuale delle conoscenze circa gli argomenti che furono discussi (mesoni τ, mesoni K, iperoni carichi, particelle Λ^0, frammenti nucleari eccitati, osservazioni con ca-

mere di Wilson, jets e sciami penetranti, questioni tecniche), e si potè anche giungere a stabilire convenienti e generali proposte per la normalizzazione delle misure relative agli eventi osservati nelle emulsioni fotografiche.

I testi delle comunicazioni, o dei riassunti, a seconda di quanto è stato messo a disposizione dai rispettivi Autori, sono riuniti in questo fascicolo, secondo l'indice particolareggiato dei *Rendiconti* dato a pag. 163.

In seno al Congresso venne poi costituito un certo numero di Comitati speciali, col compito di collazionare i risultati relativi ai singoli argomenti e riferirne nella seduta finale, nella forma più adatta alla discussione e alla valutazione comparativa. Le relazioni di questi Comitati sono riportate per esteso in questo fascicolo, aggiornate in base alle discussioni che da esse hanno avuto origine. Riteniamo che esse rappresentino un contributo concreto del Congresso alla precisazione degli argomenti in discussione. Un vivo plauso deve essere rivolto perciò ai componenti dei Comitati per l'utilissimo lavoro svolto.

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La ricchezza e l'importanza dei risultati presentati al Congresso documentano il successo dell'ultima spedizione di Sardegna. L'idea di questa spedizione e della precedente del 1952, eseguite giovandosi di una vasta collaborazione europea, nacque a Bristol nel Dicembre 1951, in una riunione promossa dal prof. C. F. POWELL, in base alla considerazione che lo studio delle nuove particelle instabili, o di altri eventi più rari dei raggi cosmici, implica ormai un impegno di mezzi finanziari e di uomini che esorbita dalle possibilità di un solo o di pochi laboratori. È la stessa considerazione che già in precedenza, e su scala più vasta, aveva portato alla creazione del CERN. La nuova iniziativa venne perciò posta sotto gli auspici del CERN stesso e si sviluppò col favore degli organi direttivi di questo.

Già la prima spedizione, compiuta fra la primavera e l'estate 1952, per quanto organizzata nel giro di pochi mesi, fu abbastanza fortunata, e procurò una discreta quantità di buon materiale d'osservazione a vari laboratori. Inoltre essa fornì gli elementi per la più elaborata organizzazione della spedizione del 1953. Entrambe le spedizioni ebbero la base a Cagliari, che apparve particolarmente indicata, tenuto conto della premessa che i lanci si volevano effettuare nella regione mediterranea e in condizioni tali che il materiale esposto venisse a cadere in mare.

Condizione essenziale al buon successo, anzi alla possibilità stessa della spedizione in tale forma, fu l'aiuto dato dalle Autorità militari italiane, che misero a intera disposizione per tutto il tempo necessario (e furono mesi) sia una nave da guerra ed un aereo per il recupero del materiale dal mare, sia le attrezzature e il personale specializzato dell'aeroporto di Elmas per l'esecuzione

dei lanci dei palloni e per la localizzazione radiogoniometrica di questi durante il volo. Anche il Consiglio Nazionale delle Ricerche fu largo di aiuti.

Una relazione illustrativa delle due spedizioni, con particolari tecnici e dati finanziari, è allegata in appendice, a pag. 480 di questo fascicolo.

* * *

Colgo l'occasione per ringraziare vivamente, a nome di tutti gli interessati, gli Enti e le persone che hanno cooperato al successo delle due spedizioni.

Ringrazio anche il Consiglio Nazionale delle Ricerche e l'Università di Padova per il concorso alle spese di organizzazione del Congresso e la Direzione del *Nuovo Cimento* per avere accolto l'invito di dedicare alla pubblicazione di questi *Rendiconti* un numero del *Supplemento*.

AVVERTENZE

a cura della Direzione del *Nuovo Cimento*

Il Congresso di Padova rivelò nella presentazione dei vari lavori e, soprattutto, nelle discussioni che ebbero luogo per la compilazione delle *Relazioni* sui vari tipi di particelle e per fissare le proposte di normalizzazione (*), l'opportunità di unificare le abbreviazioni, i simboli, le sigle, le notazioni che più frequentemente ricorrono nella descrizione qualitativa e quantitativa degli eventi nucleari, particolarmente di quelli sorpresi in emulsioni fotografiche.

In questo senso al Congresso stesso fu già avanzata qualche proposta: per esempio circa le sigle da usare per indicare gli Istituti e i Laboratori dove si compiono ricerche con lastre nucleari, per i vari eventi osservati, le varie particelle riconosciute in essi, ecc. ecc..

All'atto pratico però gli articoli inviati per la stampa dai vari partecipanti al Congresso, presentavano, sotto questo aspetto puramente formale e convenzionale della unificazione delle scritture, differenze tali gli uni con gli altri, da rendere in più di un punto malagevole e malsicuro un rapido confronto tra lavori scritti da autori diversi.

La Direzione del *Nuovo Cimento* ha cercato di attuare, p r come ha potuto, questa unificazione, introducendo, in questi *Rendiconti*, uniformità di notazioni, di simboli, di sigle, di abbreviazioni ecc., in modo che quella cospicua unità concettuale che ha informato scientificamente il Congresso e vien testimoniata da questi *Rendiconti*, si rispecchi anche nella parte esteriore delle scritture usate.

In questo lavoro, che fu lungo e non sempre grato, la Direzione è stata validamente aiutata dal prof. A. BONETTI dell'Istituto di Scienze Fisiche dell'Università di Milano e dal dott. L. SCARSI, ricercatore del Consiglio Nazionale delle Ricerche, presso il medesimo Istituto; i quali, avendo partecipato attivamente ai lavori del Congresso, conoscevano bene e lo scopo e lo spirito coi quali esso era stato indetto e si era svolto. A loro pertanto un particolare e sentito ringraziamento.

Noi confidiamo che questa nostra fatica possa riuscire gradita agli autori e ai lettori, ed essere considerata anche favorevolmente, o almeno benevolmente, da tutti i fisici. Non fosse altro perchè essa può dare lo spunto a fare di più e meglio. In questo senso e con questo scopo, eventuali critiche, proposte, suggerimenti possono essere inviati al dott. Y. GOLDSCHMIDT-CLERMONT (+); il quale, guadagnatasi già la gratitudine dei fisici per la parte d'intermediario tra loro svolta, attraverso l'organizzazione del Consiglio Europeo per Ricerche Nucleari, col diffondere proposte, suggerimenti, ecc., che gli pervengano circa la tecnica delle lastre nucleari, un ulteriore titolo di merito e di gratitudine ora acquista per avere accolto il nostro invito di estendere la sua preziosa collaborazione alla nostra iniziativa.

* * *

(*) Vedi Sezioni IX e X di questi *Rendiconti*.

(+) A Ginevra, presso il Consiglio Europeo per Ricerche Nucleari (C.E.R.N.).

We give in the following the meaning of the symbols and notations of general use in the issue; the meaning of other notations of less general or particular use is given in the various papers.

1. – *Code-words indicating the Laboratories and Physical Institutes quoted in this issue.*

Be = Physikalisches Institut der Universität - *Bern.*
Bh = Brookhaven National Laboratory - *Brookhaven (N.Y.).*
Bo = Tata Institute of Fundamental Research - *Bombay.*
Br = H. H. Wills Physical Laboratory - *Bristol.*
Bth = Experimental Biology and Medicine Institute of the National Institutes of Health - *Bethesda (Maryland).*
Bx = Laboratoire de Physique Nucléaire, Université Libre - *Bruxelles.*
Ch = Department of Physics University of Chicago - *Chicago (Ill.).*
Du = School of Cosmic Physics, Dublin Institute for Advanced Studies - *Dublin.*
Ep = Laboratoire de Physique de l'École Polytechnique - *Paris.*
Ge = Istituto di Fisica dell'Università - *Genova.*
Go = Max-Planck-Institut für Physik - *Göttingen.*
It = Department of Physics and Nuclear Studies, Cornell University - *Ithaca (N.Y.).*
Ko = Institute for Theoretical Physics, University - *København.*
Loi = Imperial College of Science and Technology - *London.*
Lu = Department of Physics of the University - *Lund.*
Mi = Istituto di Scienze Fisiche dell'Università di Milano e Sezione di Milano dell'Istituto Nazionale di Fisica Nucleare - *Milano.*
Mlb = Department of Physics, University of Melbourne - *Melbourne.*
Mn = The Physical Laboratories, University - *Manchester.*
Os = Department of Physics, University - *Oslo.*
Pd = Istituto di Fisica dell'Università di Padova e Sezione di Padova dell'Istituto Nazionale di Fisica Nucleare - *Padova.*
Pes = Laboratoire de Physique de l'École Normale Supérieure - *Paris.*
Rc = Department of Physics, University of Rochester - *Rochester (N.Y.).*
Re = The Weizmann Institute of Science - *Rehovoth (Israel).*
Ro = Istituto di Fisica dell'Università di Roma e Sezione di Roma dell'Istituto Nazionale di Fisica Nucleare - *Roma.*
To = Istituto di Fisica dell'Università di Torino e Sezione di Torino dell'Istituto Nazionale di Fisica Nucleare - *Torino.*
Ws = U. S. Naval Research Laboratory. - *Washington (D. C.).*
Ww = Institute of Physics, University of Warsaw - *Warsaw.*

2. – *Symbols for the particles or nuclear events observed in nuclear emulsions.*

The symbols for fundamental particles are as suggested in *Nuovo Cimento*, **11**, 213 (1954).

Phenomenological notations for particular cases are given in the Reports of the Committees, Section X of this issue.

The neutron and the nuclei of H-isotopes are indicated with lower case roman (n, p, d, t).

N indicates nucleons; F indicates nuclear fragment (or heavy primary).

A particle, or sometimes the nuclear event which contains that particle, is represented by the symbol of the particle, followed by the code-word of the Laboratory or Institute in which the particle has been observed. Examples: τ-Br$_1$ = the first τ-meson observed by the Bristol group; Y-GeMi$_6$ = the sixth hyperon observed by the Genova and Milano group. The symbols of the particle can be omitted, when the omission does not give rise to misunderstandings.

3. – *Notations referring to the properties of the particles and of the nuclear processes in which the particles are involved.*

M, m	rest mass.
$\mathrm{m_e}$	electron rest mass (as unit).
E	kinetic energy.
p	momentum in the laboratory system.
p^*	momentum in the center of mass system.
p_t	transverse momentum.
β	ratio between the velocity of the particle and the velocity c of light.
Z	electric charge (in elementary units).
τ	mean life.
ϑ_p, θ_p	angle to the primary.
φ	angle between the tracks in V^0-events.
Q	energy release in decay or disintegration processes.

4. – *Notations referring to the measurements on the particles.*

L	length of a track.
R	residual range.
t	time of flight.
g	grain or blob density.
g^*	grain or blob density relative to «plateau» density; in many cases g (or g^*) without further specification has been used to indicate ionization measurements.
G	gap density or mean gap length.
D	multiple scattering mean sagitta.
α	multiple scattering mean angle.
$\bar{\alpha}_{100}$	multiple scattering mean angle on 100 microns cells.
(α, R)	mass determination from scattering and range measurements.
$(g\ R)$	mass determination from grain or blob density and range measurements.
(G, R)	mass determination from gap density and range measurements.
(g, α)	mass determination from grain or blob density and scattering measurements.
(G, α)	mass determination from gap density and scattering measurements.

As it is said on pag. 170, criticisms and suggestions about these symbols and notations should be sent to Dr. Y. Goldschmidt-Clermont, C.E.R.N., Geneva, who will kindly circulate them through them C.E.R.N. organisation.

The Study of Heavy Unstable Particles Using Stripped Emulsions. Introductory Remarks.

N. DALLAPORTA

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

The new technique of stripped emulsions, which enables us to follow particles which take part in nuclear interactions over a much longer path length than ever before, has opened many new possibilities in the realm of problems which we hope may be solved with photographic plates. A number of important advantages have been gained as regards the research on heavy unstable particles produced by the cosmic radiation. Some early results presented during the Bagnères Conference, have already given a very impressive example of the possibilities offered by this new technique. This has now been confirmed on a much larger scale by the experience obtained with their own emulsion stacks by all the laboratories which took part in the Sardinian balloon flights of summer 1953, and which are now meeting here to discuss the first results obtained. In order to give an idea of the technical progress achieved, it may be sufficient to mention that until recently, it was only in exceptionally lucky cases that one could follow back a heavy meson to its point of origin in a nuclear event; now, however, this has become the normal case. For practically all of the unstable particles that have been observed in stripped emulsions, we now know both the characteristics of the event from which they emerge and the mode of their decay. And, whereas in the past almost all the identifications were obtained by combined measurements of ionization and multiple scattering, now the much greater length of the tracks available allows one in many cases to follow the particles to the end of their range, so that the determination of their identity is achieved through range-ionization or range-scattering measurements, thereby permitting much more precise results.

As a consequence of these increased possibilities of analysis, we may divide

the problems that are faced by the emulsion technique into the following two groups: 1) those which may be considered as already almost resolved, or at least easily resolvable in a short while with the stacks that are now available; this is the case when the ranges of the particles are generally not longer than the dimensions of the present stacks; 2) problems in which the interesting tracks are much longer than the dimensions of the stacks; then the plates will not give answers which can be considered certain, and the associated problems will probably require more refined methods for their final solution.

As an introduction to this conference, we will review briefly some of the more important questions with which we are faced, by considering them from this point of view, with the help of some elements which may give positive indications when the available experimental data are as yet inadequate.

The τ-Meson.

Considering the group of those particles whose mass is about 1 000 m_e, it seems quite natural to single out the τ-meson, which from the beginning has assumed a privileged position as it is one of the very few particles which decay into charged secondaries only. For this reason and because of the rather low Q-value, the τ disintegrations are very clearly events of the first group, and we can reasonably hope that for these particles the results obtained with the present plates will be adequate to give us all the information that the plate technique may disclose about this particle. The data gathered in the different laboratories which will be discussed later have given, first, very exact determinations of the Q-value. Secondly, τ-decay events are now beginning to be sufficiently numerous to make possible the determination of the angular distribution and energy spectra of the secondaries, which, when accurately known, will give indications on the nature of the τ and on its coupling with the π field. Thirdly, if we assume (as the experimental data seem to suggest), that all τ-mesons decaying in the plates are positive, we may soon hope to have a sufficient number of secondaries with known charge to be able to construct indipendent energy spectra for both positive and negative π-meson prongs. From the theoretical results of DALITZ, FABRI and TOUSCHEK we know that now the shape of the spectra obtained by separating the prongs with different sign are very sensitive to the type of the field and to the coupling scheme. It is then reasonable to expect that only through increasing these statistics shall we be able to resolve this important problem concerning the nature of a heavy meson.

The more general picture concerning the mode of decay of the τ has been recently completed by the discovery of events of S-type, whose primary has a mass comparable with the τ mass and whose ionizing secondary is a π-meson

with an energy that is different in each case and never exceeds the upper limit of the charged secondaries of the τ. This strongly suggests that these events may be interpreted according to the scheme

$$\tau'^{+} \to \pi^{+} + \pi^{0} + \pi^{0},$$

which should represent an alternative mode of decay of the τ, already theoretically foreseen by DALITZ. The ratio of the number of decays of this new type to the normal mode of τ-decay seems at the present time compatible with what may be expected from theoretical considerations. Photographic plates, however, are not very suitable for the detection of the two π^0 assumed to be emitted in this decay; perhaps only a lucky photograph in Wilson chamber with plate absorbers may be able to give us an answer.

Other K-Mesons.

In contrast to the case of the τ-meson, we do not think, on the basis of present evidence, that a clear picture of the behaviour of the other K-mesons which appear as S-events in the plates has as yet been obtained. This is essentially due to the fact that in general the secondary of these events is rather energetic and does not come to the end of its range in the stack; and that the energy measurements made on those secondaries seem to indicate a continuous spectrum of values. This evidently favours the hypothesis of a three body decay (one charged and two neutral) at least in some cases; and this idea seems to be confirmed by some examples with a low energy charged decay particle; but on the other hand it has not yet been possible to make certain that monoenergetic decay particles are not included with those having a continuous spectrum. Evidently we cannot yet feel sure about the energy spectrum of the secondary, and it is still much more difficult to ascertain its identity; we can say that in general these secondaries are « light » mesons, but only exceptionally has it been possible to decide whether they are π or μ. These circumstances furthermore make impossible the use of the conservation theorems to determinate the mass of the primary; therefore, values of it may be obtained only by direct measurements (range-ionization or range-scattering), which, although they are good enough to give a right idea of the order of magnitude of the mass, are quite inadequate to resolve more detailed and refined problems. We are not sure if there are different mass values for the K's or if, less probably, a single mass value for the K may also be identified with the mass of the τ; and consequently, if the different types of events are to be considered as different modes of decay of the same particle or if there are many different particles. Of course, the statistical mean values for the

mass obtained for many particles have no real meaning in this problem, as it is by no means certain that the different decay modes on which we build our mean value are effectively all of the same type and are not a superposition of different particle decays. It is thus clear that although we can hope that some particularly fortunate event may shed some light on the question, we are facing here a problem of the second group, for which it does not seem that the experimental technique has as yet furnished the best means for its solution.

The numerous considerations which arise from these questions are far too complex and intricate to summarize briefly; undoubtedly they will constitute an important part of the discussions which will follow. Here it will suffice to mention only some of the current ideas.

It has been about two years since the Bristol group proposed the following schemes of decay for the K-particles:

$$(1) \qquad \varkappa \to \mu + ? + ?$$

$$(2) \qquad \chi \to \pi + ? \qquad E_\pi \sim 110 \text{ MeV.}$$

The first of these may be considered as confirmed in that more than one event of this type has now been observed in the plates with a rather low energy μ secondary that ends in the emulsion. As for the second mode of decay, the high energy π has of course not been able to be brought to the end of its range within the emulsion. I am not aware if further evidence regarding this sort of decay has now been obtained.

If the events with a high energy secondary which do not fulfill the requirement of scheme (2) are to be interpreted as the high energy part of the continuous μ spectrum of scheme (1), we have to face the problem defining the upper limit of this spectrum. If the mass of the K were identical with the mass of the τ, this limit would be 150 MeV. Some events seem to be well beyond this limit; in this case, at least some types of K should have a mass higher than the τ mass.

This general situation, already complicated enough, has recently been made more complex by the postulate of a new decay scheme, proposed by the École Polytechnique group, to interpret some S-events of the Wilson chamber which they have recently observed. Although the experimental data relative to these events do not exclude a three body decay, the Paris group prefer to propose the following scheme:

$$(3) \qquad K_\mu \to \mu + \nu \qquad p_\mu \sim 220 \text{ MeV/c.}$$

Of course, because of the high energy of the secondary in this monoenergetic

scheme, there doesn't seem to be much hope to distinguish it from the other schemes (1) and (2). And of course, direct measurements of the masses of the primaries could scarcely help to discriminate between them.

We may conclude that, in the present situation, it may well be that all the S-events observed in plates as K-decays are really a mixture of those different possible schemes. We are therefore awaiting with much interest the conclusions that have been reached on this problem by the different laboratories that have worked on the plates flown in Sardinia and by cloud chamber evidence.

The Negative K.

Naturally, either the knowledge of their mode of decay in two or three bodies, or the indications of the identity of the still quite unknown neutral secondaries would be of fundamental importance to distinguish the types of K-particles that we observe; that is, if they are bosons or fermions or a mixture of both types, thus indicating if they interact more or less strongly with nuclei. This can be determined either by direct observation of the effects of the neutral secondaries or by the behaviour of the negative K, that is, by the existence of nuclear disintegrations caused by the capture of negative K's at the end of their range.

For the determination of the nature and number of neutral products of the disintegration, photographic plates offer very few possibilities. The most interesting results have so far been obtained by Wilson chambers with plate absorbers and it is known that the MIT group has detected the production of photons associated with S-events. We are expecting to hear some information on recent developments in this very interesting and important subject. I don't believe however that it has been possible until now to establish clearly the origin of these photons.

The plates however have ascertained the existence of stars resulting from K capture. As far as we know, there are actually a number of rather different estimations of the relative frequencies of these events as compared with the K-decays. Nevertheless, it seems rather certain that, even considering the high experimental losses which for a long time have hidden the existence of those stars, their frequency is certainly much lower than that of K-decays. This would lead us to think that either a part only of the K's, probably the negative τ's, are able to interact with nuclei, while the others though negative, could decay even when bound in atomic orbits; or conversely, that there is a large positive excess among the K's (for example it should not be forgotten that all the S-events observed by the Paris group that decay in Wilson chamber are positive). It is possible that an exact determination of the frequencies

of the different types of events, obtained by summing the results of the different laboratories, would be one of the more interesting results of this conference. These frequencies have so much more meaning now, in that most of the heavy mesons that decay or are captured also have their origin in the same stack, so that the frequencies of production practically coincide with the frequencies of the events.

The Neutral Hyperon Λ^0.

Considering now the results obtained regarding the hyperons, we may say that the same favoured position occupied by the τ-meson with respect to the other K-particles is held also by the neutral hyperon Λ^0:

$$\Lambda^0 \to p + \pi^- \qquad Q \sim 37 \text{ MeV}. \tag{4}$$

This is due of course to the fact that this hyperon decays into two charged particles and that its Q-value is such that both decay products frequently end in the emulsion. This fact makes it possible for us to consider also the Λ^0 as events of the first group, and as far as we know, we think that the data already obtained on Λ^0 decaying entirely in plates will result in the exact determination of the Q-value and of the mass of this hyperon. Increased statistics of the events, as in the case of the τ, will presumably make possible in the near future a more detailed picture, as regards, for instance, the energy emission spectrum of the Λ^0 from the events in which they originate.

This rather extended knowledge, which we may hope to achieve in a rather short time, allows us to use these same Λ^0 events for the interpretation of more involved phenomena in which they are thought to take part. In particular we are thinking of those events in which nuclear fragments from nuclear interactions contain a bound Λ^0 which on decaying provokes the disintegration of the whole fragment. The detailed study of this type of event, which seems to be better interpreted by this explanation than by any other, will give us the possibility of studying the excited nucleons in their relations with other normal nucleons in nuclei.

The other Hyperons.

Though the frequency of charged hyperons seems to be definitely lower than the frequency of K-mesons, and even though only few examples have been observed in nuclear plates, we may say that the results obtained up to now in this field appear to be rather clearer than those discussed previously

concerning the K-mesons. This may seem somewhat surprising at first glance if we remember that the hyperons will appear in the plates as the K, i.e. as S-events, or, in more unfavourable cases, as V-events decaying in flight. The explanation lies, perhaps, in the fact that all the schemes that until now have been proposed to interpret these events postulate a two body decay with a definite Q-value; and this seems, in fact, to be the case. The following decay modes have been suggested:

$$\left.\begin{array}{lll} (5) & Y^{\pm} \rightarrow \pi^{\pm} + n & \\ (6) & Y^{+} \rightarrow p + \pi^{0} & \end{array}\right\} Q \sim 120 \text{ MeV.}$$

To these schemes we may add another two which seem to explain some of the events that have been observed in the Wilson chamber:

$$(7) \qquad \Lambda^{+} \rightarrow \pi^{+} + n \qquad Q \sim 40 \text{ MeV}$$

$$(8) \qquad Y^{-} \rightarrow \Lambda^{0} + \pi^{-}$$

and there are perhaps some more, for which evidence is actually gathering. We may try to fit the data we possess, even though scarce, into a possible theoretical scheme, which, if valid, would give us a means to foresee other events of the same type not yet observed, and which could therefore be considered as a useful research tool for further investigation.

The isotopic spin formalism, originally proposed to express in a synthetic way the different types of nuclear forces, has found in the interpretation of the scattering of π-mesons by nucleons an important field of application, which underlines its physical significance, and it now seems the most natural way of expressing the hypothesis of charge indipendence of nuclear forces. It would therefore also seem possible to try to interpret the different types of hyperons as different possible charge values of given excited states of nucleons. These, of course, will correspond to half-integer values of the isotopic spin. If, then, this concept has any basis in fact we should expect, if we attribute the minimum possible value 1/2 to the hyperon with a Q-value of 37 MeV, that this hyperon would exist in two charge states:

$$\Lambda^{+}, \quad \Lambda^{0}.$$

Some of the decays observed in Wilson chamber concerning the hyperon with a value of 120 MeV have revealed that this particle may have a negative charge; it is therefore necessary to attribute to this hyperon an isotopic spin of at least 3/2, and this implies that it should be observed in the following

four states of charge:

$$Y^{++}, \quad Y^{+}, \quad Y^{0}, \quad Y^{-}.$$

Finally, the hyperon that decays according to scheme (8) (and which according to it must have a mass some 200 m_e greater than the preceding one) has till now been always observed in a negative state, and must therefore have also an isotopic spin of at least 3/2; it then must also exist in four different charge states similar to the preceding ones.

If all of the hyperons already detected find their place in the preceding picture, there would be many possible charge states that have not yet been observed. Evidently, there may be some experimental bias which make it difficult to observe some possible cases; but this does not happen for all of them. It would then seem to be useful to examine the possible experimental aspects of those decays as yet unobserved, for this may indicate a possible approach for further progress in this field. The discovery of these new events would have a considerable influence on the ideas we have on nuclear forces.

Altogether, we believe that the results concerning the hyperons even though of a preliminary character, may be considered as promising and we may expect with some confidence that a further contribution to this problem may be obtained from the present plates.

My aim was not to give a general review of the problems associated with heavy unstable particles, but rather to focus attention on some of its most important aspects, which the plates now available allow us to study. Thus, some very important items concerning the general situation of heavy mesons have not even been mentioned, as for example, the θ^0 meson which decays into two π, and which owing to its very high Q-value, has little chance of being detected or studied with plate technique, at least in its present stage of development. And of course the closely connected problem of its possible generation together with the Λ^0 hyperon in some nuclear events, seems equally to be out of the range of plate technique. Neither have we spoken of mean life estimates, as these are generally poorly studied with plates, except for very small values. Rather, the fact which has been already pointed out, that in general the unstable heavy particles observed in the actual stacks have their origin in a nuclear disintegration in the same stack, may prove to be a powerful tool in the obtaining of information in the near future (when sufficient statistics have been gathered) about the modes of origin of these heavy particles, and the establishment of some possible correlations in the simultaneous production of charged heavy mesons or hyperons. We hope that the results which will be presented by the various laboratories, will be of sufficient weight to allow a new appraisal and orientation of the situation regarding heavy mesons and associated problems to be made.

SEZIONE II

Mesoni τ

Contribution to the τ-Meson Investigation.

E. Amaldi, G. Baroni, G. Cortini, C. Franzinetti and A. Manfredini

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

1. – Introduction.

In the emulsions exposed at high altitude during the Balloon Flights International Expedition held in Sardinia in 1953, we have observed 4 more examples of τ-mesons on whose measurements we report here.

The remarkable advantage of the use of stripped emulsions with respect to the usual nuclear plates is quite evident in such a type of investigation: in all four cases it was possible to follow the track of the τ-meson back to the star in which it was originated and the tracks of 9 among the 12 π-mesons emitted in their decay process, come to an end inside the emulsions.

Therefore it was possible, in all these 9 cases, to establish the sign of their electric charge by recognizing if they gave rise to a typical $\pi \rightarrow \mu \rightarrow e$ process or to a star.

In section 2 we discuss the Q-value and the mass of the τ-meson. The still scanty information about the spin and parity and the mean life of τ-mesons are collected in sections 3 and 4, and in section 5 we compare the observed frequency of τ-decay with the frequency of $\pi^{\mp}$ coming to rest inside the emulsion.

2. – The Q-Value and the Mass of the τ-Meson.

The more relevant data about the decay process of our 4 τ-mesons, are collected in Table I. In the first part of it we give the ranges R of the π-meson with their errors, the corresponding kinetic energies E, the number n of emulsions crossed by each decay product which stops in the emulsion, and the process of decay or interaction observed at the end of its range.

TABLE I. *Data on the disintegration of 4 τ-mesons.*

Particle	R (μ)	n	$(\delta R\cdot 10^2)/R$ Straggling	Distortion	Thickness	E (MeV)	Decay or capture	θ_i	$\sum \theta_i$	$c\cdot 10^2$	Q (MeV)
τ-Ro$_3$	7350	12	2.7	1.1	0.06	19.4 ± 0.33	$\pi \to \mu \to e$ therefore π^+	$138°26' \pm 2°$	$359°51' \pm 3°$	97 ± 12	74.4 ± 1.3
	4370	4	2.8	2.3	0.26	14.4 ± 0.30	σ_1 » π^-	$148°57' \pm 30'$			
	$\gtrsim 4000$	—	—	—	—	—	—	$72°28' \pm 1°50'$			
τ-Ro$_4$	31900	14	2.26	0.6	0.04	46.2 ± 0.62	$\pi \to \mu \to e$ therefore π^+	$32°41' \pm 16'$	$359°50' \pm 1°$	93 ± 10	74.2 ± 0.7
	4180	2	2.8	1.8	0.07	14.1 ± 0.27	σ_1 » π^-	$163°46' \pm 21'$			
	4120	4	2.8	2.4	0.30	13.9 ± 0.30	$\pi \to \mu \to e$ » π^+	$163°23' \pm 11'$			
τ-Ro$_5$	$\gtrsim 6350$	—	—	—	—	—	—	$76°10' \pm 20'$	$359°50' \pm 1°$	95 ± 6	74.1 ± 0.9
	10650	13	2.6	1.3	0.36	24.1 ± 0.40	σ_3 therefore π^-	$131°40' \pm 35'$			
	2510	1	2.9	—	—	10.5 ± 0.18	$\pi \to \mu \to e$ » π^+	$152° \pm 30'$			
τ-Ro$_6$	2117	3	3.0	3.6	0.64	9.5 ± 0.26	$\pi \to \mu \to e$ therefore π^+	$146°25' \pm 2°$	$359°50' \pm 4°$	97 ± 24	77 ± 4
	12940	15	2.5	1.2	0.27	27.0 ± 0.43	$\pi \to \mu \to e$ » π^+	$88°27' \pm 2°30'$			
	$\gtrsim 12200$	—	—	—	—	41 ± 4 (1)	— —	$125° \pm 2°30'$			

(1) Measured by means of grain density variation with range.

TABLE II. – *Comparison between various determinations of the Q-value.*

	τ-Ro$_3$			τ-Ro$_4$				τ-Ro$_5$		
	$E_2, \theta_1, \theta_2, \theta_3$	$E_1, \theta_1, \theta_2, \theta_3$	E_1, E_2, θ_3	$E_2, \theta_1, \theta_2, \theta_3$	$E_1, \theta_1, \theta_2, \theta_3$	$E_3, \theta_1, \theta_2, \theta_3$	E_1, E_2, E_3	$E_3, \theta_1, \theta_2, \theta_3$	$E_2, \theta_1, \theta_2, \theta_3$	E_2, E_3, θ_1
E_1	(23.1)	19.4	19.4 (+)	(47.1)	46.2	(44.8)	46.2 (+)	(40.6)	(39.8)	(39.5) (+)
E_2	14.4	(12.0)	14.4 (—)	14.1	(13.7)	(13.3)	14.1 (—)	(25.1)	24.1	24.1 (—)
E_3	(44.6)	(37.8)	(40.6) (+)	(14.7)	(14.3)	13.9	13.9 (+)	10.5	(10.0)	10.5 (+)
Q	83.1 ± 4.7	69.2 ± 7.6	74.4 ± 1.3	75.9 ± 2.7	74.2 ± 1.3	72.0 ± 1.7	74.2 ± 0.7	76.2 ± 3.4	73.9 ± 1.7	74.1 ± 0.9

A detailed discussion of the errors involved in the range measurements and the corresponding kinetic energy determination is given in Appendix I.

In the second part of Table I we give the angles θ_i, in space, between the pairs of tracks (j, k), their sum as a very rough estimate of the coplanarity, and a coefficient of coplanarity

$$c = \frac{\varepsilon}{2\pi}, \tag{1}$$

where ε is the spherical excess (see Appendix II).

In the last column we give the values of Q.

In the case of event Ro_6 we did not attempt a very accurate determination of the Q-value because one of the tracks goes out of the emulsion and the local distorsion is so high that after correction (see Appendix II) the errors in the angles are quite appreciable. The given Q-value is simply the sum of the kinetic energies of the 3 π-mesons as they appear in colum 6: for the first two π-mesons the kinetic energy was determined from their ranges, while for the third one it was determined from the grain density variation along the range. For each one of the other 3 events we have measured the energies of at least two of the three π-mesons and the 3 angles θ_i with rather good accuracy. Therefore we can get, as usual, for each one of them, various determinations of the Q-value. A few of them are given in Table II where at the head of each column are indicated the experimental data used; the kinetic energies given in brackets are calculated making use of the conservation of momentum.

In various cases we have made use of the kinetic energies of a particle and of all three angles θ_i; if one makes use of only 2 angles θ_i, as is always possible assuming $\sum \theta_i = 2\pi$, one gets the same value of Q and only a slightly different error.

While the agreement between the various determinations of Q is always very satisfactory for events Ro_4 and Ro_5, in the case of Ro_3 two values differ by 1.6 times their quadratic errors. Such a deviation however does not appear to be too serious.

As has already been pointed out by other authors [1] the best determination of the Q-value seems to be that based on as many range measurements as possible, probably because by such a procedure one averages in some way with respect to the errors introduced by the straggling. The values of Q given in Table I have been chosen according to this remark.

Taking a weighted average (*) of the Q-values given in Table I we get

$$Q = 74.2 \pm 0.5 \text{ MeV} = 145.21 \pm 0.98 \text{ m}_e, \tag{2}$$

(*) Averages have been calculated with weight inversely proportional to the square of the errors.

which is appreaciably lower (1.1 times the error) than the value reported previously [2] as a weighted average of the results on 11 τ-mesons observed in various laboratories.

In order to compare our result with that of other authors we have collected a few other measurements obtained recently in various laboratories, making use of stripped emulsions [1, 3-8]. Most of these data have been circulated in the form of private communications and therefore we can not be sure that they are definitive. In some cases the error was not stated clearly and therefore we had to evaluate it.

If, in spite of these remarks, we take a weighted average of 12 Q-values so collected, we obtain

$$Q = 74.3 \pm 0.3 \text{ MeV} = 145.40 \pm 0.63 \text{ m}_e , \tag{3}$$

in excellent agreement with the value (2).

Combining (2) and (3) we can conclude that the best value, to our knowledge, that can be obtained to-day by the elaboration of data collected with the stripped emulsion technique is

$$Q = 74.3 \pm 0.3 \text{ MeV} .$$

In order to get the mass of the τ-meson we make use of the recent measurements of the masses of π^+ and π^--mesons [9]. Taking

$$m_{\tau^+} = 2m_{\pi^+} + m_{\pi^-} + Q = (819.3 \pm 0.4) \text{ m}_e + Q ,$$

one gets, from (2) and the value of the mass of the electron [10]

$$m_{\tau^+} = 964.5 \pm 1.1 \text{ m}_e \tag{4}$$

and from (3)

$$m_{\tau^+} = 964.7 \pm 0.8 \text{ m}_e = 492.9 \pm 0.4 \text{ MeV} , \tag{5}$$

which is appreciably lower than the value stated previously [2] mainly because of the reduction of the mass of the $\pi^{\pm}$-mesons.

3. – About the Spin and Parity of τ-Meson.

The energy spectrum of π-mesons emitted in the decay of τ-mesons is obviously connected with the intrinsic properties of this particle [2]. This

problem has been investigated by DALITZ [11] who tried to obtain as much information as possible independently of the charge of the emitted π-mesons. However with the use of stripped emulsions technique it is now often possible to establish the sign of all 3 π-mesons emitted in the τ-meson decay. Consequently it became necessary to reconsider the problem taking into account the more detailed information which is beginning to be collected.

This problem has been treated independently by FABRI [12] and DALITZ [13]. Although the contents and results of these two papers are very similar, we will refer mainly to the paper of FABRI for two reasons. First the calculations of FABRI are relativistic without introducing any considerable complication. Secondly FABRI suggests a very simple rule which allows the consequences of various hypotheses on the spin and parity of the τ-meson to be compared with experimental data even if these last are statistically rather poor.

Referring to the original paper [12] for details, we will simply recall that the FABRI rule consists in giving, for various values of spin and parity, the frequencies with which the energy E_3 of the unlike π-meson falls in 3 « regions » defined as follows:

region	a	$E_3 > E_1 > E_2$
»	b	$E_1 > E_3 > E_2$
»	c	$E_1 > E_2 > E_3$

where E_1 and E_2 are obviously the energies of the two equal mesons.

The data available to-day are statistically so poor that no definite conclusion can be drawn. The importance of the problem however is such that we think it interesting to discuss it although only some uncertain information can be derived.

We dispose of only: a) 4 examples (Pd_3, Ro_4, To_1, To_2) of τ-mesons for which the sign of the charge of all 3 π-mesons is known, and b) 3 examples (Bo_1, Br_5, Ro_6) in which we know the charge of only two out of three π-mesons, but the two are equal (both positive). Therefore we have only 7 cases in which we can establish in which of the three FABRI regions falls the energy E_3 of the unlike (negative) π-meson.

If we assume, as it seems plausible (see later) that all τ-mesons are positive, we can slightly enlarge our statistics because we can make use of the following 9 examples: Br_1, Bo_2, Ro_3, Ro_5, Br_6, Br_7, Rc_1 (*), Rc_2, Bth_1.

Under this assumption we dispose of 16 cases. Furthermore one has to

(*) In this event, known to us through private communication, only the negative charge of a π-meson of 7.5 MeV is known. As in the case of Br_1, from conservation of energy and momentum one can state that both other π-mesons must have a larger energy.

notice that in event Ro_4 the energy of the π^+ is so close to the energy of one of the two π^- that one cannot exclude that it may be put in region c) instead of region b). Therefore we have to consider 2 possible distributions in the 3 Fabri regions which we will indicate in the following as case A and case B.

In case A we have: in region a) 5, in region b) 5, in region c) 6; while in case B: in region a) 5, in region b) 4, in region c) 7.

From the experimental errors on the energies of the π of event Ro_4 one can calculate that the distribution A has a larger probability than the distribution B ($P_A = 0.69$; $P_B = 0.31$).

By applying the χ^2-test to these two distributions with respect to the theoretical values calculated by FABRI, one gets the results collected in Table III. In the first column appear the values of the spin and the parity, in columns 2

TABLE III. – *χ^2-Test on the spin and parity of τ-mesons.*

Spin and parity	$P_A = 0.69$		$P_B = 0.31$	
	χ^2	P	χ^2	P
[0 –]	0.1	$\lesssim 1$	0.9	$\lesssim 1$
[1 +]	7.2	0.03	11.1	0.004
[1 –]	4.8	0.09	7.7	0.024
[2 +]	1.9	~ 0.4	1.9	~ 0.4
[3 –]	0.8	$\lesssim 1$	2.3	~ 0.3

and 4 the values of χ^2 of the two experimental distributions A and B with respect to the FABRI theoretical values, and in columns 3 and 5 the corresponding values of the Pearson function P. From the inspection of the table one can conclude that the case that appears to be less probable, at the moment, is [1 +] to which follows [1 –].

Before closing this section we would like to discuss the existing evidence for the assumption that all τ-mesons decaying in emulsion in 3 charged π-mesons are positive. In Table IV we have collected all the information available on the charge of the π-mesons produced in the decay of τ's. The few cases observed in usual nuclear plates are marked with an asterisk, and the corresponding numbers are in brackets. All other events have been observed in stripped emulsions.

Apart from the poverty of the statistics it is rather difficult to make any quantitative statistical consideration for the following reasons: first the observation or non-observation of one of the 3 π-mesons emitted in the τ-decay is not independent of the observation of the other two, and secondly we do

not yet know if the unlike meson has a different energy spectrum from the other two. If it is so, there will be some experimental bias in the collected data.

TABLE IV. – *Data on the charge of the decay products of τ-mesons.*

Observed charge of τ-mesons	Numbers of particles	Particles
+ + −	4	Pd_3, Ro_4, To_1, To_2
+ −	7	Bo_2, Ro_3, Ro_3, Br_6, Br_7, Rc_1, Bth_1
+ +	2	Bo_1, Ro_6
+	3 + (2)	Bo_3, Br_4, Ep_1, Ro_1 (*), Mi_1 (*)
−	1 + (1)	Rc_2, Br_1 (*)

(*) τ-mesons observed in usual nuclear plates; all the others have been observed in stripped emulsion.

In spite of these remarks we have tried to draw some conclusions from the data of Table IV in the following way.

Let us consider the universe of all τ-mesons that stop in the emulsion and decay in 3 charged π-mesons and call p and $q = 1 - p$ the probability for any one of these particles to be positive or negative respectively. We note that q is obviously related to the probability that a negative τ-meson undergoes a nuclear capture once at rest inside the emulsion.

If N is the number of τ-mesons for which we have observed the charge of all 3 decay products, we can write that the probability that at least N' of them are positive, is given by the relation

$$\sum_{N'}^{N} {}_x \frac{N!}{(N-x)!\,x!} p^x q^{N-x} . \tag{6}$$

Let us call now n the number of τ-mesons for which we have observed the charge of only one of its 3 decay products: the probabilities of observing a π^+ or a π^- are given respectively by the two obvious expressions

$$\left\{\begin{aligned} p' &= \frac{\frac{2}{3}pe + \frac{1}{3}qu}{(2e+u)/3} = \frac{2e}{2e+u}p + \frac{u}{2e+u}q \\ q' &= \frac{\frac{1}{3}pu + \frac{2}{3}qe}{(2e+u)/3} = \frac{u}{2e+u}p + \frac{2e}{2e+u}q , \end{aligned}\right. \tag{7}$$

where e and u represent the average efficiences for detection of one of the two equal π-mesons and of the unlike one respectively.

The probability of having observed at least m positive π-mesons out of n, is given by

$$\sum_{m}^{n}{}_{y} \frac{n!}{(n-y)!\,y!}\, p'^{y} q'^{n-y}\,. \tag{8}$$

The product of (6) and (8) gives the probability $P(p, e, u)$ of having observed at least N' positive out of N τ's whose charge is known, and at least m positive out of n π's whose charge is known.

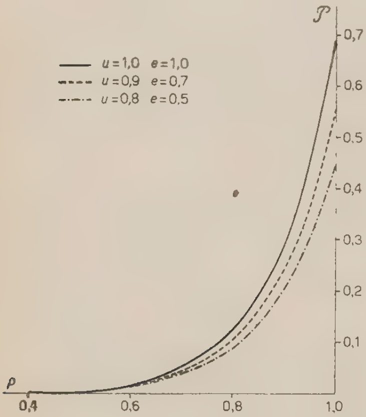

Fig. 1.

From Table IV we see that in our case $N - N' = 4 + 3 = 7$ because all events $(++-)$ and $(++)$ belong to this class, and $n = 2 + (2) + 1 + (1) = 6$, $m = 4$. The only class of events that cannot be used in this consideration is that of type $+-$.

In Fig. 1 we have plotted P as a function of p for the 3 following cases: $e = 1$, $u = 1$; $e = 0.7$, $u = 0.9$; $e = 0.5$, $u = 0.8$. In fact we notice that out of 15 cases, 7 fall in the region c) of FABRI. That means that we have to expect a bias of the experimental data which favour the observation of the unlike π-meson.

As can be seen from the figure, the probability of observing the set of events of Table IV is greater than 10% only for values of $p \gtrsim 0.8$.

4. – About the Mean Life of τ-Mesons.

A few considerations about the frequency of observation of τ-mesons have allowed [14, 15] to establish that the mean life of this particle must be longer than 10^{-9} s.

A direct determination of the mean life could be made by means of the statistical method suggested in the case of hyperons [16] which however needs the observation of a few τ-mesons decaying in flight.

To our knowledge there is no case of τ-meson observed in emulsion to decay in flight. Therefore we can only confirm the conclusions of other authors mentioned above that the mean life of τ-mesons is probably longer than 10^{-9} s by the following elementary considerations. The moderation-time t that a particle takes to cover a range R until it is reduced to rest, is obviously

$$t = \int_0^R \frac{\sqrt{1-\beta^2}}{c\beta}\, \mathrm{d}R = \frac{M}{c} \int_0^{R/M} \frac{\sqrt{1-\beta^2}}{\beta}\, \mathrm{d}\frac{R}{M}\,, \tag{9}$$

which, considering that the quantity

$$(10) \qquad r = \frac{R}{M}\,,$$

is a function of β, reduces to

$$(11) \qquad t = MF\left(\frac{R}{M}\right),$$

with

$$F(r) = \int\limits_0^{r(\beta)} \frac{\sqrt{1-\beta^2}}{\beta}\,\frac{\mathrm{d}r}{\mathrm{d}\beta}\,\mathrm{d}\beta\,.$$

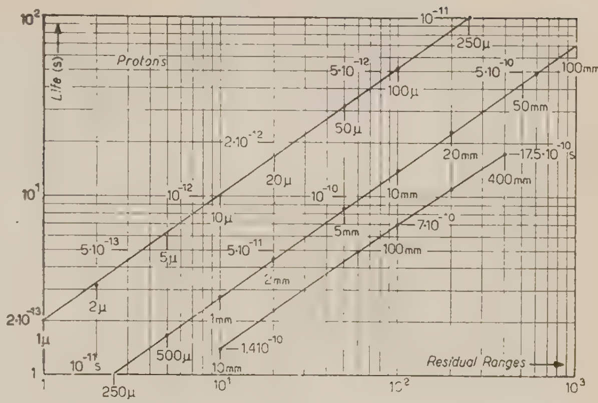

Fig. 2.

In Fig. 2 we give t/M in seconds, as a function of r in micron of emulsion. M is measured in protonic mass.

The graph has been obtained making use for $\beta \lesssim 0.4$ of the non relativistic relations

$$\frac{T}{Mc^2} = \frac{1}{2}\beta^2\,, \qquad \beta = \frac{1}{42.2}\,R^{0.287}\,,$$

$$\frac{t}{M} = \frac{1}{c}\int\limits_0^R \frac{\mathrm{d}R}{\beta} = 1.97\cdot 10^{-13}\left(\frac{R}{M}\right)^{0.713}, \qquad \left(\frac{R}{M} < 2\cdot 10^4\mu\right),$$

while for $\beta \geqslant 0.4$ it has been calculated numerically by means of eq. (11). In this region the following empirical formula can be used: $t/M = 2.76\cdot 10^{-11}\cdot(R/M)^{0.708}$; where R is expressed in mm.

Table V contains the times of moderation of a few τ-mesons.

Table V. – *Observed moderation time of τ-mesons.*

Particle	$t\cdot 10^{10}$ s	Particle	$t\cdot 10^{10}$ s	Total moderation time
Ro_1	0.6	Bo_1 (*)	0.11	$t_{\text{total}} = 1.53\cdot 10^{-9}$ s
Ro_2	0.5	Bo_2 (*)	0.87	$t_{\text{stripped}} = 1.19\cdot 10^{-9}$ s
Ro_3 (*)	1.4	Bo_3 (*)	0.95	
Ro_4 (*)	1.1	Pd_1	1.00	
Ro_5 (*)	1.43	Pd_2	0.79	
Ro_6 (*)	0.75	Pd_3 (*)	0.87	
		Mi_1	0.57	
	5.78	To_1 (*)	2.74	
		To_2 (*)	1.66	
			9.56	

The cases indicated with an asterisk are those observed in stripped emulsions. The total moderation time of the τ's collected in Table V is 10^{-9} s. Of these, 10 have been observed in stripped emulsions for a total moderation time of $1.19\cdot10^{-9}$ s. That means that in average these 10 mesons have lived a time of $1.19\cdot10^{-9}/10 = 0.12\cdot10^{-9}$ s between the moment of their generation and the moment in which they were reduced to rest. This average time of moderation ($\sim 10^{-9}$ s) is presumably shorter than that which we would obtain if the volume of the emulsion were infinite, because we have certainly lost an appreciable number of τ-mesons with range larger, and only very few with range shorter than the observed average range.

Therefore we can conclude that the total time of moderation corresponding to the 30 odd τ-mesons observed until now in emulsions, corresponds to about $3.6\cdot10^{-9}$ s.

5. – Frequency of Observation of τ-Meson Decay.

The 4 τ-mesons reported above have been observed scanning systematically 27.15 cm³ of emulsion. In 3.94 cm³ of emulsion we have observed 44 π-mesons giving a star of 2 or more prongs ($\sigma \geqslant 2$); 40 $\pi \to \mu$ decays and 64 events which could be σ_1 or $\pi \to \mu$ decays.

Making use of the two following relations [17]

$$N_{\sigma_{\geqslant 2}} = 0.377\, N_{\sigma_{\text{tot}}}$$

$$N_{\sigma_1} = 0.324\, N_{\sigma_{\text{tot}}}$$

we get

$$N_{\pi^-} = N_{\sigma_{\text{tot}}} = \frac{44}{0.377} = 106\,,$$

$$N_{\sigma_1} = 0.324\cdot 106 = 34.4$$

$$N_{\pi^+} = 40 + (64 - 34.4) \simeq 70$$

$$N_{\pi^-} + N_{\pi^+} = 106 + 70 = 176$$

and taking into account the volums scanned

$$\frac{N_\tau}{N_\pi} = 3.3\cdot10^{-3}\,,$$

to be compared with $3.5\cdot10^{-3}$ given in our previous paper [2].

This figure compares very well with that given by PETERS and coworkers [1] if one considers that these authors find 1.1 ± 0.8 per cent for the ratio of the number of τ and π-mesons which are generated and stop inside the emulsion. According to the same authors the fraction of π-mesons which stop and are generated inside their emulsions is about 1/2 the total number of π-mesons that simply stop inside the emulsion.

APPENDIX I

The sources of error on the range determination which appear to be more important and which have been considered, are the following: straggling, distortion, true thickness of the emulsions and possible reduction of emulsion thickness during their processing.

a) Straggling. The straggling has been calculated by means of the usual formulae [18] which have been checked in the case of μ-mesons as explained in the following.

The root mean square deviation corresponds, in all the cases considered, to 2.3-3.0% of the mean value of the range.

b) Distortion. The distortion of the emulsions can give rise to a variation of the horizontal projection of a track whose magnitude and sign depend on the value and orientation of the distortion vector. When the track of a particle comes to its end in the same emulsion we have measured the local distortion and correspondingly corrected its range (that has been done, for instance, in the case of the third of the π's of Ro_5).

When the track crosses a rather large number of emulsions instead of correcting for the distortion we have preferred to evaluate the corresponding error in the following way.

We have measured the distortion vector S_{0i} in $m = 11$ emulsions of our stack and he have checked that their orientations were roughly at random. We considered therefore justified the assumption of isotropic orientation of the distortion with respect to the direction of a track and we have calculated the mean square deviation of the range R of a track which is observed in n emulsions

$$\text{(A1)} \qquad \left(\frac{\delta R}{R}\right)_{\text{distortion}} = n^{\frac{1}{2}} \frac{s}{R} \sqrt{1 - \left[\frac{(n-1)d}{R}\right]^2} \,,$$

where $d = 600\ \mu$ is the average thickness of the emulsions and

$$\text{(A2)} \qquad s = \sqrt{\frac{1}{2} \sum_{1}^{m}{}_i S_{0i}^2 \Big/ m} \,,$$

is the root mean square of the component of S_{0i} in a given direction, which turns out in our case ($m = 11$) to be 54 μ.

c) *Thickness of the emulsions.* Following the procedure used by other authors [1] we have measured the fractional variation of the various emulsions with respect to their average thickness, and we have found that only in one case it amounted to 4.6% while in all other cases it was not more than 2.5%. The root mean square deviation turns out to be 2.3%.

The corresponding error in the range determination is

$$\text{(A3)} \qquad \left(\frac{\delta R}{R}\right)_{\text{thickness}} = n^{\frac{1}{2}}(n-1)2.3\cdot 10^{-2}\left(\frac{d}{R}\right)^{2}.$$

One can easily see that in all the cases considered in this paper the error due to this effect is smaller than that due to the straggling and distortion.

d) Finally we have considered the possibility that during the elimination of the silver layer deposited on the surface of the emulsions, that is made at the end of the development, an appreciable reduction of the thickness of the emulsion could take place. In fact by inspecting the various determinations of the Q-value reported in the literature or circulating in form of preprints, one notices that in general the values obtained with stripped emulsions are slightly lower than that obtained with the usual nuclear plates. Therefore we were looking for the possible existence of some systematic error which could justify this remark.

One can however easily show that the error introduced by the above mentioned reduction of thickness is always negligible with respect to that due to the variation of the original thickness of the emulsions. This point was also checked by measuring the range of a few μ-mesons emitted by π-mesons at rest which passed from one emulsion to the next one with a rather small angle of dip.

As a conclusion of this discussion we think that the main error in our range measurements is due to the straggling and distortion while the other causes give a negligible or almost negligible contribution.

The corresponding errors in the kinetic energies E_π have been calculated as usual making use of the relation $E_\pi \sim R^{0.575}$. Before making use of any range-energy relation we have checked the stopping power of our emulsions by measuring the ranges of 12 flat μ-mesons produced in $\pi \to \mu$ decay processes. The mean value of the ranges obtained is

$$\text{(A4)} \qquad R_\mu = (594 \pm 6)\,\mu$$

to be compared with $R = 595\,\mu$ obtained from the table given by VIGNERON [19] for μ-mesons of kinetic energy $E_\mu = 4.12$ MeV [9]. The given error represents the standard deviation. The corresponding mean square deviation represents 3.5% of the average range. Such a value has to be compared with 4.9% obtained by FRY and WHITE [20] and 3.7% calculated with the same formulas used above for the straggling of the π-mesons. Therefore we have used for the range-energy relation the table of VIGNERON up to $E_p = 200$ MeV and the curves calculated from the range-energy relations for Al and Pb using the method suggested by PETERS and coworkers [1].

APPENDIX II

Also the angles between the projections of the tracks of the 3 π-mesons in the plane of the emulsions (α_{ij}) and their dips (φ_i) have been measured with great care.

The correction of the α_{ij} due to the distortion has been made following the procedure suggested by other authors [1]. Such a correction was in general small and therefore the error given for the true angles θ_i between the tracks in space have been calculated taking into account only the errors of readings. In the case of event Ro_6, the correction due to the distortion was rather large and therefore the corresponding error on the θ_i have been calculated taking into account also the error on the distortion vector.

In order to check the coplanarity of the 3 π-mesons emitted in a τ-meson decay, the quantity

$$\sum \theta = \theta_1 + \theta_2 + \theta_3 ,$$

seems to be rather unsensitive. Therefore we have used the parameter

$$c = \frac{\varepsilon}{2\pi} , \tag{A5}$$

where

$$\varepsilon = \gamma_1 + \gamma_2 + \gamma_3 - \pi , \tag{A6}$$

is the spherical excess and γ_1, γ_2, γ_3 the angles between the planes of the 3 pairs of π-mesons. Finally we give a few elementary formulae which can be useful for expressing ε and its error by means of the measured quantities.

$$\cos \gamma_i = \frac{\cos \theta_i - \cos \theta_j \cos \theta_k}{\sin \theta_j \sin \theta_k} ,$$

$$(\delta\varepsilon)^2 = \frac{1}{A} \left\{ \sum_{1}^{3}{}_i \, (M_{ij} H_{ij} + M_{ik} H_{ik})^2 \Delta\varphi_i^2 + \sum_{1}^{3}{}_i \, N_i H_{jk}^2 \Delta^2\alpha_{jk} \right\} ,$$

where

$$A = 1 - \cos^2 \theta_1 - \cos^2 \theta_2 - \cos^2 \theta_3 + 2 \cos \theta_1 \cos \theta_2 \cos \theta_3 ,$$

$$M_{ij} = \cos \varphi_i \sin \varphi_j - \sin \varphi_i \cos \varphi_j \cos \alpha_{ij} ,$$

$$N_i = \cos \varphi_j \cos \varphi_k \sin \alpha_{jk} ,$$

$$H_{ij} = \frac{\cos \theta_i + \cos \theta_k}{1 + \cos \theta_k} - 1 .$$

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Analysis of some τ-Mesons.

G. BELLIBONI, B. SECHI and B. VITALE

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

During the present investigation three τ-mesons have been observed (to be indicated by the symbols Pd_3, Pd_4 and Pd_5) decaying at rest into three charged π-mesons, which are emitted in a common plane with a total kinetic energy of about 75 MeV; and a fourth event, indicated as $^{(\tau)}K_\pi$-Pd_1 [1], which is probably an example of the alternative mode of decay of a τ into one charged π-meson and two neutral particles.

Two of the τ-particles were observed during the general scanning of the plates; the other two, one of which was the $^{(\tau)}K_\pi$, were observed in a systematic investigation, in which both π^+ and π were followed from the end of their range towards their origin. From these results we have obtained the following frequencies for τ-mesons:

a) from « following back »:

1 τ-meson for every 67 π^+ coming from stars
or for every 174 $\pi^+ + \pi^-$ coming from stars;
1 $^{(\tau)}K_\pi$ for every 67 π^+ coming from stars
or for every 174 $\pi^+ + \pi^-$ coming from stars.

b) from « general scanning »:

1 τ-meson for every 1 100 $\pi^+ + \pi^-$ observed,
or 0.14 $\tau/\text{cm}^3\cdot\text{day}$.

The details of the 4 τ-particles have been collected together and listed in Table I. Each of the τ-particles has its origin in a nuclear disintegration produced in the emulsion layers of the stack. These parent stars have been studied: every charged particle has been followed in an effort to establish the

TABLE I. – τ-*Mesons.*

		τ-MESON						SECONDARIES							
Particle	Stack	Mass (α, R) (m_e)	E (MeV)	Parent star	ϑ_p	Sign	Time of flight (s)		Range (mm)	E (MeV)	Identity	Angles		Q (MeV)	Notes
τ-Pd_3	S6	—	32	21 + 13p ($\sim$25 GeV)	17°	+	$0.9\cdot10^{-10}$	a	25.2 ± 0.3	40.5	π^+	α	72°	75.0 ± 1.1	Coplan. $\pm1°$
								b	12.9 ± 0.1	27.4	π^+	β	130°		
								c	1.3 ± 0.01	7.1	π^-	γ	158°		
τ-Pd_1	S27	—	35	10 + 1p ($\sim$2 GeV) (*)	40°		$1.0\cdot10^{-10}$	a	>9.0	34.2		α	100°	76.0 ± 1.5	Coplan. $\pm1°$
								b	12.3 ± 0.5	26.4	π^-	β	120°		
								c	4.7 ± 0.2	15.2	π^+	γ	140°		
τ-Pd_5	S6	—	45	16 + 4n ($\sim$5 GeV) (**)	—		$1.4\cdot10^{-10}$	a	>6.0	33.5		α	100°	75.6 ± 2.0	Coplan. $\pm1°$
								b	9.2 ± 0.5	22.5	π^-	β	128°		
								c	7.2 ± 0.4	19.6	π^+	γ	132°		
$^{(\tau)}K_\pi$-Pd_1	S27	966 ± 100	48	8 + 3n	—		$1.5\cdot10^{-10}$	c	0.9	6.0	π^+				

(*) Slow π^--meson is emitted from the parent star.
(**) The τ-meson is emitted at an angle of 35° with respect to the axis of the shower.

Fig. 1.

Observer: G. MARINOLLI

co-production of other heavy-mesons, and an estimate of the energy of the star based on the charged particles emitted has been made. For each τ-decay the range and angle of emission of each secondary particle was measured and the angles between the secondaries were determined. Using the most accurately measurable parameter the Q-value for each decay was determined.

The errors in the Q-values listed were determined considering errors in range measurement and straggling, and errors in the measurement of the angles between the secondary tracks [2]. The favourable conditions afforded by the stripped emulsions have allowed us to determine the Q-values without having to rely on measurements of specific ionization. The Q-value for those events in which only two of the secondary particles came to the end of their range in the emulsion layers were determined assuming that all three particles were π-mesons.

τ-Pd_3 (Fig. 1): This was the first example of a complete τ^+-event; the two π^+-mesons and the π^--meson came to rest in the emulsion layers. The Q-value was determined using only the ranges of the secondary particles; however, values determined using any one energy and the measured angles agree, within the error, with the quoted Q-value. The secondary tracks are co-planar to within 1°.

τ-Pd_4: The τ-particle in this event decayed into a π^+-meson, a π^--meson and a third particle which left the emulsion stack before coming to rest. Because of the large angle scattering of the π^--meson about 1 mm before the end of its range the Q-value was determined using the energy of the π^+ and the angles between the secondary tracks. The decay is co-planar to within 1°.

τ-Pd_5: This event is also characterized by the fact that two of the products, a π^+-meson and a π^--meson, come to the end of their range in the emulsion, the third leaving the stack before coming to rest. The Q-value was determined from measurements of the range of the π^+ and π^--mesons and the angles between the secondary tracks. The coplanarity to within 1° of the three secondaries has been demonstrated.

The average Q-value, weighted on the inverse of the square of the relative errors, is

$$Q = 75.4 \pm 0.8 \text{ MeV} .$$

Taking [3]

$$m_{\tau^+} = (819.3 \pm 0.4)\ m_e + Q ,$$

we obtain

$$m_{\tau^+} = 967.1 \pm 2.0\ m_e .$$

${}^{(\tau)}K_{\pi}$-Pd_1 (Fig. 2): The heavy meson was emitted at a specific ionization of 3.6 times the minimum value. After a range of 13 mm it came to rest and decayed. The secondary charged particle after 0.9 mm came to the end of its range and decayed into a μ-meson, which in turn came to rest after a range

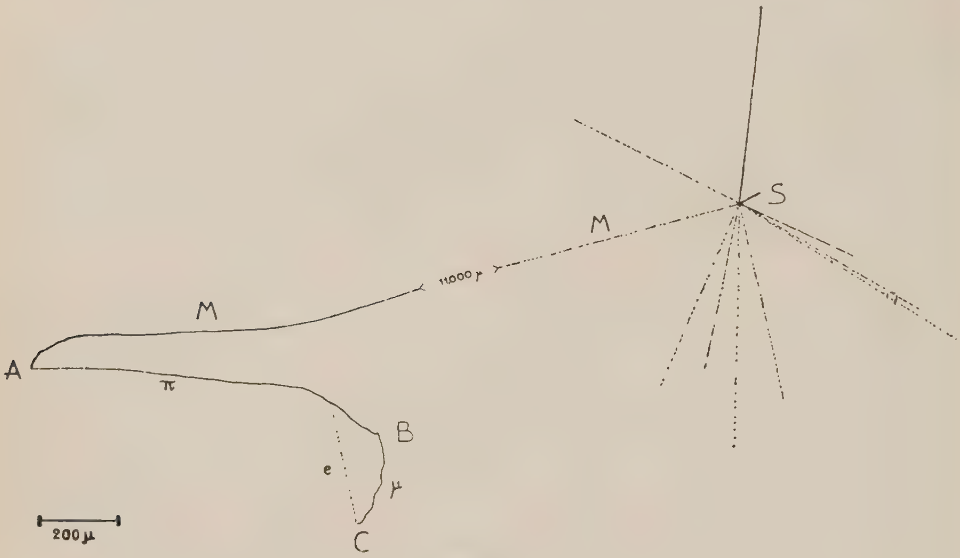

Fig. 2.

of 0.6 mm and decayed. The possibility for this event to be actually an example of a $K \to \mu$ decay has also been considered, however the discontinuity in both scattering and ionization 0.9 mm from the end of its range, and the fact that the mass of the particle decaying into a μ-meson, as determined by range-scattering measurements over 0.9 mm of its range, is $200 \pm 70\ m_e$, leads us to conclude that this particle is a π^+-meson and that the decay is of the type:

$${}^{(\tau)}K_{\pi} \to \pi^+ + \text{at least one neutral particle.}$$

This event could be interpreted as an example of the nuclear capture of a K^--meson, the absorption being followed by the emission of a π^+. It would seem reasonable to assume in this case that the K^- would be absorbed by a nucleon pair and the process may therefore be written:

$$K^- + p + p \to n + n + \pi^+ \,.$$

It would seem, however, that the absorption of a meson by a pp pair is very improbable (this is the case, at least, for the absorption of the π^- [4]).

Because of the very complex decay implied in this scheme we have concluded that this event is the decay of a τ^+ into a π^+ meson and two or more neutral particles. The decay scheme: $\tau^+ \rightarrow \pi^+ + \pi^0 + \pi^0$ has already been predicted in theoretical calculations [5] and some events which were interpreted with this scheme have been observed in the past few months by several laboratories [6].

Some General Considerations on τ-Mesons.

We have initiated a general analysis of the principal characteristics of τ-mesons and their decay. The statistics that are actually utilizable are very small; and it is only possible to give some results of a rather indicative nature. Actually we have based our analysis on 25 decays at rest (Bo_1, Bo_2, Bo_3; Br_1, Br_2, Br_5, Br_6, Br_7, Br_8, Br_9; Loi_1, Loi_2, Loi_3; Mi_1; Mn_1, Mn_2; Pd_1, Pd_2, Pd_3, Pd_4, Pd_5; Ro_1, Ro_2; To_1, To_2).

The problemes that we will consider here are the following:

a) production of τ-mesons;
b) charge of τ-mesons which decay at rest in photographic emulsions;
c) energy spectrum of the decay pions of τ-mesons.

a) *The Production of τ-Mesons.* – Of the 25 disintegrations considered, 12 have their origins in nuclear disintegrations occurring in the stack. The parent star is characterized on the average by a type: $12 + 5$, but has a wide distribution in the number of shower particles ranging from 0 to 16 per star. For these stars, which are produced by charge one primaries (6 events) or by neutral primaries (4 events), or by α-particles (2 events), there seems to be no apparent relationship between the number of black and grey tracks and the number of shower particles.

Remembering that the average parent star in which K-mesons appear is $15+5$ (15 events), we note that there is no significant difference when compared with that of the τ-mesons. There is however, for the « parent » stars of the K, a more regular form for the curve resulting from the plot of the number of shower particles versus number of grey and black tracks.

The energy spectrum of production of the τ-mesons considered has a maximum in the energy range from 30 to 40 MeV. Of these 12 events, 5 are in this region and the remaining 7 are distributed from 7 to 110 MeV. This marked peak in the spectrum may still have its explanation in an exceptional statistical fluctuation, however it may be noted that the corresponding spectrum for K-mesons (15 events) has a completely regular form.

It has not been possible to give information on the angular distribution of the emitted τ-meson either with respect to the vertical direction or the

direction of the primary, because very few laboratories communicated this data. This type of analysis may be of some importance in the study of the mechanism of production of τ-mesons, at least when the number of events is sufficiently large.

b) The Charge of the τ-Mesons Decaying at Rest in Photographic Emulsions. – Of the 75 pions from the decay of the 25 τ-mesons considered here, 30 come to rest in the emulsion layers thus making possible a determination of their charge; 21 are positive, 9 negative. For 5 of the τ-mesons it has been possible to establish the charge; all were positive.

On the basis of this data it is possible to calculate in two independent ways the most probable percentage of positive τ-mesons in the total number. These calculations which will now be discussed are based on following hypotheses:

1) the percentage of τ^+ in the sample considered corresponds to the percentage of τ^+ in the world of τ-mesons;

2) the energy spectra of the positive and negative pions from the decay are the same, and therefore the probability that a pion comes to the end of its range in the emulsion is independent of its charge;

3) the sign of the charge of the pions whose range ends in the emulsions is identified with certainty.

Basing on these hypotheses and indicating by x the fraction of positive τ-mesons it is possible to show that the probability for a pion to be either positive ($P(\pi^+)$) or negative ($P(\pi^-)$) is independent of the percentage of τ that give respectively, one, two or three secondaries ending in the emulsion, and that:

$$P(\pi^+) = \tfrac{1}{3}\cdot(1+x)\;; \qquad P(\pi^-) = \tfrac{1}{3}\cdot(2-x)\,.$$

The probability, for the 30 pions ending in the emulsion, that the distribution of + and — coincides with that calculated is given by Bernoulli's law and is obviously a function of x. The values calculated have been listed in the third column of Table II.

The probability that of the 5 τ-mesons we should find 5 positive is given by x^5. This value for varying values of x is also listed in the fourth column of the table.

One notes that, while the lowest percentages of τ^+ are certainly excluded, the experimental data which we have used, based only on statistical considerations on the sign of the pions ending in the emulsion, do not seem to exclude the possibility that 20 to 30% of the decays appear as decays of τ^--mesons. We may therefore conclude that, probably, $x \geqslant 0.7$-0.8.

TABLE II.

$a = N_{\tau^+}/N_{\tau^-}$	$x = N_{\tau^+}/N_\tau$	$P(21+,\ 9-)$	$P(5+)$
0.00	0.0	$3.6\cdot10^{-5}$	0
0.11	0.1	$1.7\cdot10^{-1}$	$1\ \ \cdot10^{-5}$
0.25	0.2	$6.5\cdot10^{-1}$	$3.2\cdot10^{-1}$
0.43	0.3	$2.1\cdot10^{-3}$	$2.4\cdot10^{-3}$
0.67	0.4	$5.8\cdot10^{-3}$	$1.0\cdot10^{-2}$
1.00	0.5	$1.3\cdot10^{-2}$	$3.1\cdot10^{-2}$
1.50	0.6	$2.9\cdot10^{-2}$	$7.8\cdot10^{-2}$
2.33	0.7	$5.1\cdot10^{-2}$	$1.7\cdot10^{-1}$
4.00	0.8	$8.4\cdot10^{-2}$	$3.3\cdot10^{-1}$
4.50	0.9	$1.2\cdot10^{-1}$	$5.9\cdot10^{-1}$
∞	1.0	$1.5\cdot10^{-1}$	1

c) The Energy Spectrum of the Decay Pions of τ-Mesons. – The energy spectrum of all emitted pions considered together is in good agreement with that calculated, based only on statistical considerations (the χ^2-test gives $P \sim 0.75$). If we consider instead only the positive pions we obtain a spectrum very different from the theoretical one ($P \sim 0.005$). This disagreement is due principally to the geometric factor of loss for pions with larger energies, the charge of which is difficult to determine directly; however this geometric factor seems to be present in a different way for the spectra of pions of different charge. It would therefore seem possible that the pions having different charge are emitted during the decay with different energy spectra.

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An Example of a τ^+ and of a $^{(\tau)}K_\pi^+$.

M. Di Corato, C. C. Dilworth and L. Scarsi
Istituto di Scienze Fisiche dell'Università - Milano
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

A τ^+ and a $^{(\tau)}K_\pi^+$ (or τ') (*) have been found in the systematic scanning of 17 cm³ of stripped emulsion exposed in the Sardinian flights (1953).

In Table I are given the data on the τ^+-Mi$_2$. Two of the secondaries end in the stack, giving rise to the decay $\pi \to \mu \to e$ and are therefore considered to be positive. Their energy is deduced from their range. The energy of the third secondary, necessarily negative from conservation of charge, has been calculated in three independent ways from the energy of the two π^+ and the angles between the tracks, the value given is the weighted mean of these three determinations.

The range energy relation used was that of Bradner *et al.* No calibration has been made of the stopping power of the emulsion, which is a function of the unknown water content of the emulsion at the time of exposure.

The measurement of the angle between the two tracks, and of the range is subject to error due to the deformation of the emulsion. In this case the uniform, as well as the non uniform, displacement of the various strata of the emulsion with respect to any fixed point is of importance. The uniform displacement does not produce a curvature of the tracks and is therefore not immediately measurable by the classical methods. Work is in progress to determine the extent of this deformation but in the results given here no correction is made.

The error given takes into account the errors of measurement, the incertitude in the factor of shrinkage (5%) and, for the range, the straggling. In

(*) *Report of the Committee on τ-Mesons*, in this issue, pag. 419, § 6.

TABLE I.

τ^+-Mi_2						SECONDARIES				
Range (mm)	Energy (MeV)	Parent star	Sign	Time of flight (s)	Mass (const. sag.) (m_e)	Range (mm)	Energy (MeV)	Sign	Angles	Q (MeV)
						20.208 (23 plates)	35.8 ± 1.4	+	$90^o \pm 3^o$	
14.16 (7 plates)	49	$11+10n$	+	$1.5 \cdot 10^{-10}$	785 ± 110	—	31.6 ± 2.3	(—)	$110^o \pm 5^o$	73.2 ± 3
						0.886 (1 plate)	5.8 ± 0.2	+	$159^o \pm 3^o$	

TABLE II.

$^{(\tau)}K^+_\pi$-Mi_1						SECONDARY		
Range (mm)	Energy (MeV)	Mass (constant sagitta) (m_e)	Parent star	ϑ_p	Time of flight (s)	Range (mm)	Energy (MeV)	Sign
7 (19 plates)	33 assuming $M = 965\ m_e$	600 ± 160 (only statistical error)	$17 + 7p$	37^o	10^{-10}	26 (5 plates)	41.5	+

the error given on the range of the secondary 1, an additional error has been included of 5%, being the order of magnitude of the effect of the distortion on this measurement. No such error has been attributed to secondary 3 since this track is short and lies very flat in the emulsion, nor to the measurement of the angles.

The grey and black tracks of the star in which the τ^+ was born have been followed through the stack. Among the 10 tracks which end in the stack the only other unstable particle observed was a fragment undergoing β-decay.

In Table II are given the data obtained on the ${}^{(\tau)}K_\pi^+$-Mi_1.

The value given for the mass of the primary is very rough, since the track dips steeply (47°). It has been obtained by comparison with a calibration on horizontal proton tracks (*). The correction $(\cos 47^\circ)^{0.92}$ has been applied to the mean value of the sagitta, but no correction has been made for the distortion, since it was considered useless to apply precise corrections in the case of a track of this inclination in the emulsion, in which accurate measurements are practically impossible. The error given, simply the normal statistical error, has no real significance, and is certainly a gross underestimate.

(*) M. Di Corato, D. Hirschberg and B. Locatelli: see in this issue, pag. 381.

The Phenomenological Treatment of τ-Meson Decay.

E. FABRI

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

The decay pattern of the τ-meson is most easily represented on the well-known triangular diagram. This may be done as follows: the distances of the point P (Fig. 1) from the sides of the triangle are proportional to the kinetic energies of the three π-mesons.

In consequence of the momentum conservation not every point inside the triangle corresponds to a possible decay pattern: the permitted region is defined by the equation

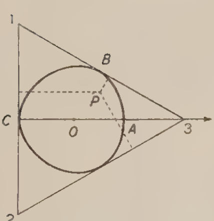

Fig. 1.

$$\varrho^2 \leqslant \frac{1}{1+\alpha(1+\varrho\cos 3\varphi)},$$

where ϱ, φ are polar coordinates in the plane of the triangle; $\alpha = \frac{1}{2}\varepsilon/(1-\frac{1}{2}\varepsilon)^2$, where $\varepsilon = E/M$, (E is the energy release of the process, M the mass of the τ-meson).

When $\alpha \to 0$, the permitted region becomes the inside of the inscribed circle; this is the case in the non-relativistic approximation.

A theory of the decay of the τ-meson will give a transition amplitude for the decay as a function of the momenta $\boldsymbol{p}_1$, $\boldsymbol{p}_2$, $\boldsymbol{p}_3$ of the three π-mesons. Instead of them, however, it will be convenient to introduce the following vectors:

$$\left\{\begin{aligned} \boldsymbol{p} &= \frac{1}{\sqrt{2}}(\boldsymbol{p}_2-\boldsymbol{p}_1) \\ \boldsymbol{p}' &= \sqrt{\frac{3}{2}}\,\boldsymbol{p}_3\,, \end{aligned}\right.$$

which, in the center of mass system, are sufficient to determine $\boldsymbol{p}_1$, $\boldsymbol{p}_2$, $\boldsymbol{p}_3$.

Corresponding to the vectors $\boldsymbol{p}$, $\boldsymbol{p}'$ we will introduce the angular moments $\boldsymbol{k}$, $\boldsymbol{k}'$, with their quantum numbers l, l'. We may now expand the transition amplitude in series of eigenfunctions of l, l'; at this point the task of the theory will be the determination of the coefficients $c_{ll'}$ in the expansion.

One can immediately say that l must be always even; taking into account the parity P of the τ, one can add that the parity of l' is opposite to that of P.

In Table I are shown the smallest values of l, l' which are permitted for given parity P and spin J of the τ-meson.

Table I.

J \ P	Even	Odd
Even	(2, 1)	(0, 0)
Odd	(0, 1)	(2, 2)

The behaviour of the transition amplitude for small values of $\boldsymbol{p}$ depends only on the minimum l, and for small values of $\boldsymbol{p}'$ on the minimum l'; one can, therefore, draw information on J and P by studying the distribution of the decay patterns in Fig. 1 in the neighbourhood of the points A and C, which respectively correspond to $\boldsymbol{p} = 0$ and $\boldsymbol{p}' = 0$.

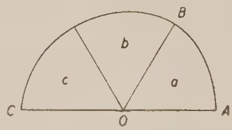

Fig. 2.

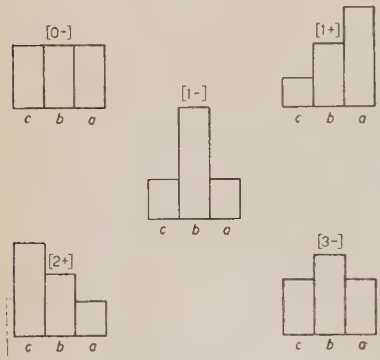

Fig. 3.

We will now assume that only the terms with the smallest values of l, l' are important, and will neglect the others. This hypothesis can be justified if one supposes that the interaction between the π-mesons is strong, only when their distance is not greater than the Compton wave length of the τ.

With this assumption one can explain the long life-time of the τ-meson, if its spin and parity are [1 —].

One can also give the distribution function in the five cases [0 —], [1 +], [1 —], [2 +], [3 —]. In order to compare these distributions with experiment, it is very useful to divide the decay patterns into three classes, according to whether the energy of the unlike meson is larger, or intermediate, or smaller than that of the other two. Calling a), b), c) the three classes so defined (Fig. 2), whe sketch in Fig. 3 their relative probabilities, calculated taking into account the relativistic corrections (which are rather important in some cases).

Report on the Bristol Group Work on τ-Mesons.

M. FRIEDLANDER

H. H. Wills Physical Laboratory - University of Bristol

Since the Bagnères Conference, six τ-mesons have been found. Three of these have been found by direct scanning, and three by following back π-mesons arrested in the stack. The preliminary data on these τ's are summarised in the Table I of the *Report of Committee on τ-Mesons* (particles Br_4, Br_5, Br_6, Br_7, Br_8, Br_9 (*)), and it must be emphasized that these are only preliminary, and that all events are to be carefully remeasured, and the best possible Q-values obtained, using ranges and angles. For the values quoted, only the ranges have been used in calculating the energies; the momentum balance has not been used yet.

(*) See in this issue, pag. 419.

Observation de mésons τ.

T. F. HOANG, L. JAUNEAU, G. KAYAS, L. LEPRINCE-RINGUET, D. MORELLET, A. ORKIN-LECOURTOIS, G. TARIEL et J. TREMBLEY

Laboratoire de Physique de l'École Polytechnique - Paris

Dans un dépouillement systématique de 24 cm³ d'emulsion « Sardaigne 22 » nous avons observé deux τ et un τ' (1); le nombre des mésons $\pi^{\pm}$ en fin de parcours est de 1018.

Dans le premier cas le méson τ est émis par une étoile du type 21+0n. Il traverse 35 emulsions et s'arrête après un parcours de 39 mm. L'un des trois secondaires s'arrête après avoir parcouru 9,633 mm et se désintègre en $\mu \to e$, tandis que les deux autres secondaires sortent du paquet. La coplanarité est verifiée à un degré près. Nous avons évalué la valeur Q par la consideration de l'équilibre des moments. Le resultat est résumé dans le Tableau I. Les erreurs de Q proviennent surtout de l'incertitude des mesures des angles.

TABLEAU I.

Angles	Parcours des secondaires	Relation Range-Energie	
		VIGNERON	BEISER
$\alpha = 123°$ $\beta = 118°$ $\gamma = 120°$	π_1: 9,633 mm	$E_1 = 22,5$ MeV	$E_1 = 23,5$ MeV
		$Q = 71,3 \pm 2,2$ MeV	$Q = 74,3 \pm 2,2$ MeV

Dans le second cas (Fig. 1) le méson τ est émis par une étoile du type 5+2n ou 5+1p. Il s'arrête après un parcours de 10 mm. Les trois π secondaires se

(1) Voir le § 6 du *Report of the Committee on τ-Mesons*, dans ce fascicule, pag. 419.

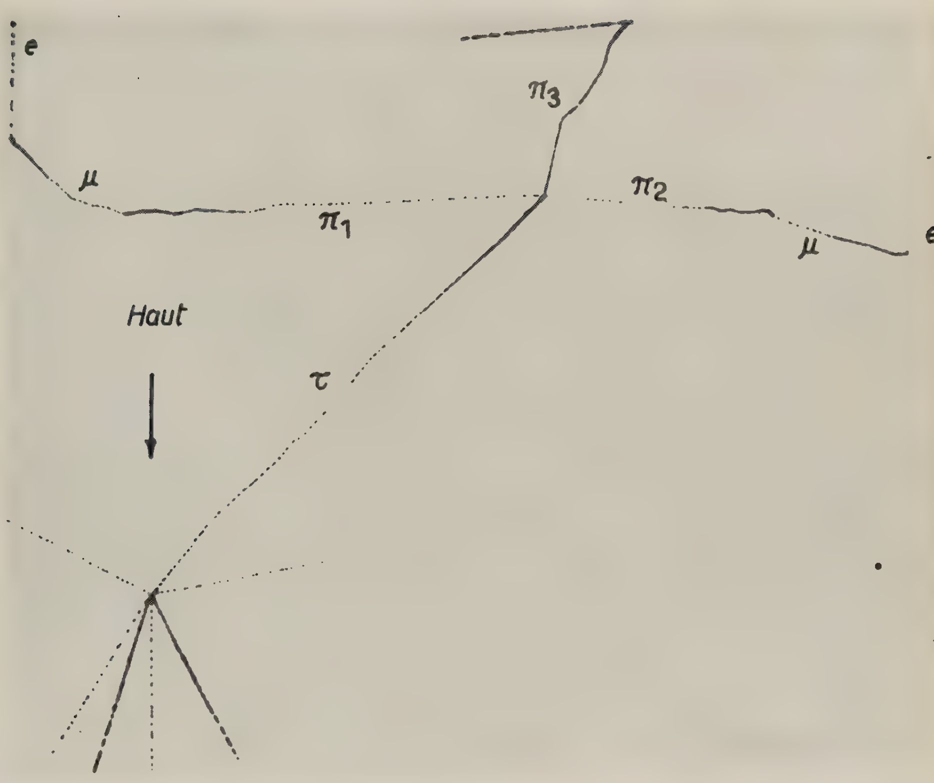

Fig. 1.

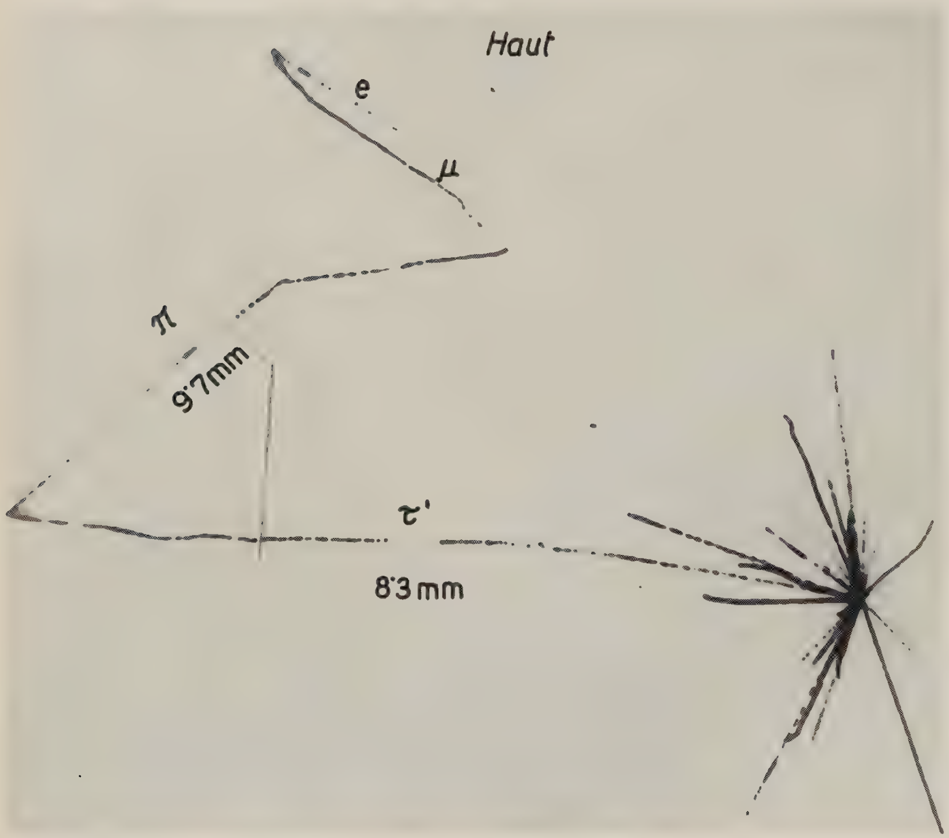

Fig. 2.

terminent tous dans le paquet. La valeur de Q calculée d'après les parcours des π est indiquée dans le Tableau II:

TABLEAU II.

Angle	Parcours des secondaires	Relation VIGNERON	Relation BEISER
$\alpha = 86^\circ$	$\pi_1^+ = 20{,}50$ mm	$E_1 = 35{,}3$ MeV	$E_1 = 37{,}5$ MeV
$\beta = 115^\circ\,30'$	$\pi_2^+ = 15{,}47$ mm	$E_2 = 30{,}1$ MeV	$E_2 = 31{,}5$ MeV
$\gamma = 157^\circ\,30'$	$\pi_3^- = 1{,}14$ mm	$E_3 = 6{,}9$ MeV	$E_3 = 6{,}9$ MeV
		$Q = 72{,}4 \pm 1{,}7$ MeV	$Q = 74{,}9 \pm 1{,}7$ MeV

Dans le troisième cas (Fig. 2) le méson τ' émis par une étoile de $21+1p$ a un parcours de 6,8 mm et s'arrête en donnant un π de 9,7 mm, lequel se désintègre en $\mu \to e$.

Les valeurs de la masse du τ' mesurée par les differentes méthodes:

photométrique	947 ± 60 m_e
des lacunes	930 ± 130 »
de la densité de grains	920 ± 80 »
du scattering	1280 ± 195 »

sont compatibles avec celle du τ. On peut interpréter ce cas comme la désintégration du τ' suivant:

$$\tau'^+ \to \pi^+ + \pi^0 + \pi^0 .$$

Mesoni K

Contribution to the K-Meson Investigation.

E. Amaldi, G. Cortini and A. Manfredini

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

1. – Introduction.

In this paper we report on a systematic investigation on K-mesons which has been made by scanning the emulsions of a stack exposed for 8 hours at about 25 000 m above sea level, during the Sardinia Expedition 1953.

In the investigation of all events consisting in two tracks showing appreciably different grain densities, we have found 4 K-mesons and 2 hyperons.

In section **2** we describe in detail the procedure followed in the grain density and scattering measurements while the detailed procedures followed for the range and gap measurements are described in other reports [1, 2]. The results of the mass determination obtained from these various measurements are discussed.

In section **3** we discuss 4 K-mesons and in section **4** we make a few very rough considerations on the stars in which K-, τ-mesons and hyperons found in this laboratory originate.

2. – Measurements.

2·1. *Grain density measurements.* – The grain density determination has been made systematically in various points of the tracks where each one of two observers counted not less than 600 grains.

We have noted that in order to get a good reproducibility of the results, it is necessary that each observer makes, in immediate succession, the measurements on the track considered and on the tracks used for calibration.

The calibration, consisting in the measurements of $g_{\min}$, has been made using the tracks of pairs of electrons which satisfied the following conditions:

a) they had to be not only in the same emulsion but also close to the considered track;

b) they had to present the same angle of dip, within a few degrees;

c) they had to be at the same depth inside the emulsion.

We have found that by applying these precautions the results of grain density determinations are quite satisfactory. In fact each measurement was always in good agreement with our calibration curve irrespectively of the experimental conditions that are generally a serious handicap in grain density measurements, such as 1) large angles of dip; 2) gradient of development in a plate; 3) different development in various plates; 4) measurement on a large range of grain density values ($1 \leqslant g/g_{min} \leqslant 4.5$).

The comparison of the results obtained by measuring the grain density in various points of the same track, gives some indication of a dispersion of the corresponding values larger than that calculated by means of the usual formula

$$\frac{\delta g}{g} = \frac{0.66}{\sqrt{n}}, \tag{1}$$

where n is the number of grains counted. This point is still under investigation.

In the meantime we follow the procedure of giving for each track the larger of the two values, one from equation (1), the other from the root mean square deviation of the various measurements with respect to their average.

2·2. *Scattering measurements.* – The measurements of scattering have been made with the sagitta method for both high velocity tracks as well as tracks of particles stopping in the emulsion. In this last case we have applied the constant sagitta scheme of DILWORTH and coworkers [3] using the calibration made in our laboratory.

All these measurements have been made twice, by comparing for each cell the first difference obtained by two different observers.

The second differences are then calculated starting from the mean values of the two determinations of the first differences, provided that these do not disagree more than expected according to the reading error. We found that with well trained observers the agreement was very seldom too poor. When that happened the corresponding group of readings was repeated immediately and corrected. We have found that with these precautions the results were very well reproducible.

The calibration of the constant sagitta method has been made with the tracks of 1 π-meson, 5 protons, 1 triton and 1 τ-meson (Ro_3), corresponding altogether to a total number of independent cells equal to 798. By applying

all usual corrections we have found

$$D = 0.568 \pm 0.015 \,,$$

in agreement with the value $D = 0.565$ given in the original paper [3]. From our results we deduce for the scattering constant the value

$$K = 24.0 \,.$$

2·3. *Results of the measurements.* – Table I contains the results of our mass determinations. As one can see the agreement between the results of various methods is very satisfactory, with the exception of the two measurements on the Y-Ro_2 [4] whose discrepancy is due to the fact that this particle decays in flight as one can also recognize from the simple inspection of its track and from the behaviour of the scattering in the vicinity of the end of its range. The residual range at the point where Y-Ro_2 decays, is estimated to be 1 mm. We hope to be able to derive more definite conclusions from a further study of this track.

The various K-particles listed in Table I show different decay products and therefore they are probably due to different particles. Their masses however are all equal within the experimental errors, so that one can attempt to make a weighted average of the masses of the K's. One gets

$$m_{\mathrm{K}} = (930 \pm 20)\ \mathrm{m_e} \,.$$

We insist on the fact that this average value has to be taken with some caution as long as it is not proved (if it ever is proved) that the events considered are due to the same particle.

3. – Decay and Nuclear Interaction.

K-Ro_1. – This event is shown in Fig. 1. The data given in Table I complete those already published in a letter to the Editor of *Il Nuovo Cimento*. In that paper, among the various possible interpretations we have considered in detail only that of a $K^- \to \pi^-$ decay [5]. This event however, can also be interpreted as due to a nuclear interaction in which, besides a negative pion only neutral particles are emitted.

Although no definitive conclusion can be reached among these two interpretations, we think it convenient to reproduce here very briefly a few arguments in favour or against each of them.

TABLE I.

Particle	Range (mm)	Mass of primary particle: (constant sagitta)	(g, R)	(g, α)	(G, R)	Mean	Secondary particle: R (mm)	g*	pβ (MeV/c)	Mass	E
K-Ro$_1$	12.1	$1\,040^{+240}_{-180}$	$1\,020 \pm 65$	—	—	$1\,020 \pm 65$	23.2	—	—	m_π (3 prongs σ)	38.5 ± 2.5
K-Ro$_2$	>24.6	—	935 ± 40	—	—	935 ± 40	>29	$\left.\begin{matrix}1.24 \pm 0.07\\1.36 \pm 0.08\end{matrix}\right\}*$	—	$\sim$ meson	$\begin{cases}\text{for } m_\pi & 103 \pm 7\\ \text{for } m_\mu & 83 \pm 5\end{cases}$
K-Ro$_3$	20.2	$1\,020^{+150}_{-120}$	860 ± 35	—	980 ± 60	900 ± 30	>18	1.07 ± 0.06	230 ± 30	$\gtrsim m_\pi$	$\begin{cases}\text{for } m_\pi & 155 \pm 25\\ \text{for } m_\mu & 160 \pm 25\end{cases}$
K-Ro$_4$	35.7	720^{+120}_{-90}	950 ± 50	980 ± 330	$1\,000 \pm 60$	940 ± 40	4.83	—	—	m_μ ($\mu \to e$)	13.6 ± 0.3
Y-Ro$_1$	4.1	$1\,840^{+530}_{-430}$	—	—	$> m_p$	$1\,840^{+530}_{-430}$	>12	< 1.5	> 100	supposed m_π	> 45
Y-Ro$_2$	32.0	†$4\,300^{+1200}_{-900}$	$2\,100 \pm 150$		-	$2\,100(\pm 150)$†	> 7.2	1.25 ± 0.08	—	» m_π	105^{+530}_{-20}

* Measured at the decay point and after 29 mm.
† The particle is not at the end of its range.

of *a*) The decay interpretation needs the assumption of a week interaction K-mesons with nucleons and that, furthermore, in the case of Ro_1, it has been captured by a light element. Against the weak interaction assumption it has been objected sometimes that from the fact that the K-mesons decay in π-mesons which interact strongly with nucleons, one would expect that also the K-mesons have an appreciable interaction with nucleons. Such an argument however is very weak because it is essentially based on the arbitrary assumption that the long mean life of K-mesons is due to some prohibition which would be destroyed by the presence of the nucleons.

b) The nuclear interaction interpretation seems to be rather improbable on the basis of the processes considered by other authors [6]. In fact with the process

$$K^- + p + N \rightarrow n + N + Q\,, \tag{2}$$

the probability of emission of only neutral particles is very small, and with the process

$$K^- + p \rightarrow n + \nu + Q\,, \tag{3}$$

the probability of emission of a π^- is very small ($N =$ nucleon, $\nu =$ light neutral particle).

One can consider, of course, other processes as has been done by TOUSCHEK whose report [7] aims to explain the mechanism of production of the very peculiar stars observed by various authors [8, 9] as due to the nuclear capture of K^--mesons.

As it appears from that report it is rather difficult to explain these stars without invoking new processes. On the other hand the number of stars of this peculiar type is doubled since our first communication on K-Ro_1. Therefore we can conclude that, waiting until a satisfactory interpretation of the stars produced by K^--mesons is found, the interpretation which reduces to a minimum the number of necessary assumptions is that Ro_1 is an extreme case of this class of events.

K-Ro_4. – This event appears to be the second example after the original particles observed by O'CEALLAIGH [10], in which the decay product can be identified with certainty from its electron decay. The kinetic energy of the secondary μ-meson of K-Ro_4 (13.6 MeV) has to be compared with a kinetic energy of 6 MeV observed by O'CEALLAIGH.

In a few other cases observed in nuclear emulsions by various authors [11, 12] the secondary particle was identified as a μ-meson, but that was only through the determination of its mass. In conclusion this event confirms the process proposed originally by O'CEALLAIGH $K \rightarrow \mu + ? + ?$ which is definitely dif-

a) b) c)

Fig. 1. – K-Ro_1 event. From left to right: *a*) the K-particle is emitted from a star; *b*) the K-particle decays with emission of a L-meson; *c*) the L-meson gives rise to a 3 prongs star (only two clearly visible in the photograph) and therefore must be a π^-.

ferent from the process considered recently by LEPRINCE-RINGUET and coworkers [13].

K-Ro_2 and K-Ro_3. – Much less can be said about these two events, because we can only state that their secondaries are L-mesons but we can not decide between π and μ-mesons. We note however that if they are π-mesons the kinetic energy of both is very close to that given by MENON and coworkers [11] for the so called χ-particles. On the other hand if the secondaries are μ-mesons only K-Ro_4 could be an example of the K_μ whose existence has been suggested by the Paris group [13].

4. – On the Stars in which K-Mesons and Hyperons are generated.

The stars in which K-, τ-mesons and hyperons originate present a particular interest because from their study and comparison with the totality of the stars observed under given conditions, one can hope to obtain some information on the process of production of the new particles.

Of course such an analysis can be fruitful only if all the experimental data collected in various laboratories are available.

We propose therefore that the data relative to stars in which K-mesons or hyperons are generated be published systematically in a standard form which shows all interesting information. Table II collects all the data on the stars in which originated the τ-, the K-mesons and the hyperons found in this laboratory.

We call the attention on the event Y-Ro_1 because no indication of a star was found at the origin of the corresponding track. Two other cases which approach this one are those of the stars in which τ-Ro_5 and K-Ro_4 are generated; in fact the total visible energy is, in both cases, almost completely concentrated in the produced K-meson.

In general it seems to us remarkable that in a collision of a primary particle with a nucleus in which a new particle is generated, or one of the present nucleons excited, it may happen so often that the excitation of the residual nucleus is so small as to escape or almost escape observation.

Another remark that we would like to stress, as it has been already done by other authors, is that the angle of emission θ of the K-meson with respect to the primary is usually very large. The corresponding angle θ^* in the centre of mass system (C.M.S.), is still larger so that one can say that at least the majority of the observed K-mesons are emitted backward in the C.M.S.

This fact is obviously due to the use of the present emulsion technique which allows the identification of K-mesons only if they have a rather small energy in the laboratory system (L.S.).

TABLE II.

Particle	Primary	Black tracks: Identity	Black tracks: R (μ)	Gray tracks: Identity	Gray tracks: R (μ)	Gray tracks: g^*	Shower tracks: θ	τ, K or Y tracks: R (μ)	τ, K or Y tracks: E (MeV)	τ, K or Y tracks: θ	Energy of stars: Visible (GeV)	Energy of stars: Evaluated from θ (GeV)
			Description of stars									
τ-Ro$_3$	α	p t	280, 1 400, 2 000 > 9 000	π^-	5 000	—	10°, 13°, 13°, 14°, 26°	13 000	46	83°	5.4	14.0
τ-Ro$_4$	α	p	286	—	—	—	14 tracks cone of total opening 30°	9 100	38	59°	13.1	> 30
τ-Ro$_5$	p	p	11, 17, 107, 5 900	—	—	—	—	13 600	47	59°	0.6	—
τ-Ro$_6$	p	p α	115, 270, 535, 704, 1 120, 3 620, 5 530 1 870	—	—	—	1°, 6°, 31°, 40°, 48°, 48°, 119°	5 300	30	150°	7.0	18
K-Ro$_1$	n	p	64, 90, 143, 176, 330, 526, 2 370, > 3 000, >4 000, >4 000, >5 300	p (K)p p p	> 8 000 >15 300 >26 500 >55 500	1.5 3.0 2.5 2.0	4°, 10°, 18°, 19°, 21°, 30°, 47°, 76°	12 100	44	47°	9.0	9.4
K-Ro$_3$	n	p	46, 50, 145, 430, 770, 1 100, 1 400, 1 900, 4 900, 6 000, 11 500, 12 200	π^+	10 000	—	25°, 37°, 38°, 43°, 43°, 46°	20 200	62	20°	6.3	2.0
K-Ro$_4$	p	p	88, 310, 410, 430, 745	—	—	—	—	35 700	84	134°	0.6	—
Y-Ro$_1$	n	—	—	—	—	—	—	4 080	34	—	—	—

This remark leads us to conclude that only a very small percentage of the generated K-mesons can be recognized in the emulsions. Therefore it would be highly desirable to be able to calculate the ratio

$$r = \frac{N_{\text{vis}}}{N_{\text{tot}}}, \tag{4}$$

of the number N_{vis} of K-mesons that are visible to the total number N_{tot} of K-mesons produced in the stars; once r is known we could deduce N_{tot} from the empirical value of N_{vis}.

The calculation of r involves however various unknown quantities such as the spectrum of the primaries of the stars in which the K-mesons are generated, and the spectrum and angular distribution, in the C.M.S.,

$$f(p^*, \theta^*)\, \mathrm{d}p^*\, \mathrm{d}\theta^* \tag{5}$$

of the produced K-mesons.

For the time being we do not like to introduce any particular assumption about the form of the function (5) as may be suggested by some one of the theories of meson production. We prefer to limit our considerations to the following extremely rough scheme which aims only to stress the role of the various quantities involved. We introduce the following assumptions:

a) the probability of observation of a K-meson in the emulsion (L.S.) is 1 if its momentum $p < p_m$, is 0 if $p > p_m$. In other words we assume the existence of a useful sphere of momentum of radius p_m in the L.S., which through the Lorentz transformation becomes an ellipsoid in the C.M.S. This ellipsoid determines two values of the momentum p_1^* and p_2^* which limit the interval in which p^* has to fall in order the corresponding p may be smaller than p_m;

b) the act in which the K-meson is generated is always a nucleon-nucleon collision;

c) we substitute the function (5) with the expression

$$4\pi p^{*2}\, \mathrm{d}p^* \qquad \text{for} \qquad p_1^* \leqslant p^* \leqslant p_2^*$$

and zero outside this interval; i.e. we assume that the K-mesons are emitted isotropically and with a spectrum which in the above defined interval is simply proportional to the corresponding element of volume in the momentum space (in the C.M.S.).

From these assumptions it follows that r is simply given by the ratio of

the volume of the ellipsoid to the volume between the two spheres of radius p_1^* and p_2^*:

$$r = \frac{1}{2}\,\frac{1-\beta^2}{3(\beta/\beta_m)^2-1}\,, \tag{6}$$

where β is the velocity of the C.M.S. in the L.S. and β_m the maximum observable velocity of the K-meson in the L.S.

If one finally assumes for the spectrum of the primaries of the K-stars, the spectrum of the primary cosmic-radiation for $E_p \geqslant 3.5$ GeV, and introduces $\beta_m = 0.55$ (corresponding to a range in the emulsion of ~ 50 mm) one gets

$$r \sim 1.6\ \% \tag{7}$$

i.e.

$$N_{\text{tot}} \sim 60 N_{\text{vis}}\,. \tag{8}$$

On the other hand let N_s be the number of shower tracks generated in a given volume of emulsion and N_π the number of π-mesons which come to rest in the same volume. Then we have the empirical relation

$$N_s \sim 6.5 N_\pi\,, \tag{9}$$

while from the data collected in Table I and the ratio (N_τ/N_π) given in our report on τ-mesons [14],

$$N_{\text{vis}} = N_\tau + N_K \sim 2N_\tau = 2\cdot 3.2\cdot 10^{-3}\, N_\pi\,. \tag{10}$$

From (8), (9) and (10) we conclude

$$\frac{N_{\text{tot}}}{N_s} \sim 0.06\,,$$

i.e. 6 per cent of the shower particles emitted in the stars are due to K- and τ-mesons. Such a value appears to be very high and is probably due to the assumption of isotropic emission of the K-mesons. In fact if the K-mesons were emitted mainly in the forward and backward direction the numerical factor appearing in equation (8) would decrease appreciably.

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Observations on K-Meson Decays.

M. Baldo, G. Belliboni, B. Sechi and G. T. Zorn

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

In the general scanning of stacks S6 and S27, eight «heavy» mesons coming to rest and decaying into a minimum ionizing particle have been observed. The identity of these particles was initially established through multiple scattering measurements at the end of their ranges in the emulsion. A detailed analysis of each of these events was then made. It consisted firstly in establishing the origin of the heavy particle, which in all cases was a nuclear disintegration occuring in the stacks, secondly in the accurate determination of the mass of the «heavy» meson, which in all cases was $\sim 1000\ m_e$, the $p\beta$ of the secondary and in two cases the mass of the secondary particle, and thirdly in the analysis of the disintegrations from which the K was emitted. The results of these measurements and analysis have been listed in Table I and will now be discussed.

The determination of the mass of the K-mesons has been made through multiple scattering-range measurements, based both on constant cell length and constant sagitta methods, and through grain density-range measurements, using as comparison tracks those produced by protons which also came to the end of their range in the emulsion layers. If the K track was steeply inclined with respect to the emulsion plane the mass value was based principally on the latter method of determination. In one case however (Pd_7), the K track was of small inclination and long range, thus permitting a rather close comparison of the two methods of mass determination: it is noted that, within statistical errors, the mass values are identical.

Through multiple scattering measurements the $p\beta$ of each secondary particle has been determined. Two of these tracks were of small dip thereby making possible a determination of the mass of the particle through measurements of «blob» density and multiple scattering. The experimental curve for π-mesons has been determined using mesons emitted from nuclear dis-

TABLE 1.

Particle	PRIMARY: Total range (μ)	PRIMARY: Time of flight (s)	PRIMARY: Mass in m_e (g, R)	PRIMARY: Mass in m_e (α, R)	SECONDARY: $p\beta$ (MeV/c)	SECONDARY: Total length in stack (mm)	SECONDARY: Mass (m_e)	STAR: Type	STAR: Estimated energy	STAR: Angle of emission of K^-	STAR: Notes
K-Pd$_3$	42 500 (95 MeV)	$4 \cdot 10^{-10}$	964 ± 60		160 ± 10	21	270 ± 33	$20 + 7n$	~ 80 GeV	101° respect to shower axis	
K-Pd$_4$	19 140 (60 MeV)	$2 \cdot 10^{-10}$	975 ± 200	961 ± 122	110 ± 15	40		$15 + 1p$	1 650 MeV visible	39°	π emitted with K
K-Pd$_5$	19 310 (61 MeV)	$2.05 \cdot 10^{-10}$	$1 006 \pm 100$	920 ± 330	70 ± 16	37.5		$4 + 1p$	910 MeV visible	121°	Energy of primary 1150 MeV π emitt. with K
K-Pd$_6$	17 240 (56 MeV)	$1.85 \cdot 10^{-10}$	850 ± 100	865 ± 292	52 ± 20			$14 + 11p$	~ 61 GeV	178°	
K-Pd$_7$	36 500 (87 MeV)	$3.5 \cdot 10^{-10}$	943 ± 60	948 ± 99	159 ± 9	24	276 ± 30	$5 + 1p$	840 MeV visible	66°	π emitted with K
K-Pd$_8$	26 924 (73 MeV)	$2.7 \cdot 10^{-10}$	$1 180 \pm 140$	895 ± 225	190 ± 40	44.4		$15 + 7\alpha$	290 GeV per nucleon	88°	
K-Pd$_9$	12 015 (46 MeV)	$1.4 \cdot 10^{-10}$	$1 060 \pm 100$	$1 420 \pm 360$	153 ± 36	21		$17 + 2p$	1 630 MeV visible	85°	
K-Pd$_{10}$	25 200 (70 MeV)	$2.5 \cdot 10^{-10}$	$1 100 \pm 160$		67 ± 15	10		$10 + 5p$	~ 75 GeV	38°	

integrations which traversed the same plates as the secondary particles and is drawn in Fig. 1. The mass values $270 \pm 33\ m_e$ and $276 \pm 30\ m_e$ determined from the calibration curve, indicate that these particles were π-mesons.

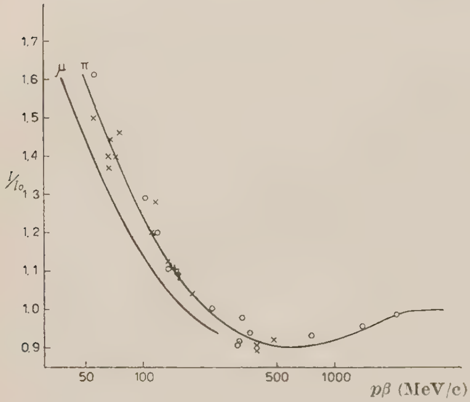

Fig. 1.

This, coupled with the fact that the secondaries have very similar $p\beta$ values, ~ 160 MeV/c, would seem to identify these particles with the « χ-mesons » initially proposed by the Bristol group. The rather precisely determined mass value of the primary particle, in both cases $\sim 950\ m_e$, is consistent with a two body scheme:

$$\chi \to \pi - \pi^0 + Q\,.$$

One of the most interesting characteristics of the disintegrations from which K-mesons are emitted is the apparently small energy involved in some of them. The disintegrations from which four of the K's are emitted have energies less than 2 GeV. These energies are « visible » energies but include the rest energy of the mesons produced. In one case it was possible to estimate the energy of the « primary » through scattering measurements on its track. This measurement gave a value of 1.1 GeV which is consistent with an estimated value deduced from the visible energy of the disintegration. For these low energy events, a characteristic that may prove to be of interest as regards the production of K-mesons is the fact that in three cases the emission of a K-meson was accompanied by the emission of a single charged pion.

Measurements on K-Mesons.

J. K. BØGGILD, J. E. HOOPER and M. SCHARFF

Institute for Theoretical Physics of the University - København

In a scan for particles which come to rest and decay or cause a star, 8 heavy mesons have been observed. Two were found in glass plates exposed during an airplane flight, one in the stripped emulsion stack H.A. 54 exposed by the Bristol group, and 5 in 11 cm³ of stripped emulsion from the latest Sardinian expedition. Seven of the K-particles decayed at the end of their range, while one caused a small three prong star. All the K-events found in stripped emulsions were traced back to the production star.

Most of the events have been found quite recently, so there has not been time to make complete measurements on all particles. The information set out in Table I must be regarded as partly preliminary. Before commenting on the results, we would like to mention that we have recently started to use a special device for gap measurement. On the eyepiece micrometer drum is mounted a wheel with 20 contacts, feeding pulses, when the hairline is moved, to a simple electrical counter. A switch near the fine focus control is operated by the left hand in such a way that the pulses are counted only when the hairline is traversing a gap. The individual gaps are thus measured by integral numbers, each representing a length of approximately 0.15 μ (by a magnification of 100×10). The method is going to be tested carefully, but we can already say that it seems to increase the speed and reproducibility of the measurements. Moreover it has the advantage, compared with other similar methods, that it does not require the track to be lined up parallel to the stage movement.

As regards the primaries, efforts have been concentrated on K-Ko_6 and K-Ko_7. The former was measured by the « P-method » of MENON and ROCHAT ($M = 960 \pm 200$ m_e) and by the « constant sagitta method » of DILWORTH *et al.* ($M = 630 \pm 190$ m_e). The mass value of 1000 ± 40 m_e was obtained by measurements of mean gap length versus range, carefully calibrated with protons. From these three methods the mass of the K-Ko_6 primary comes out

TABLE I.

	PRIMARY						SECONDARY			
	Particle	Parent star	Range (mm)	Number of plates traversed	Mass in m_e (α, R)	Mass in m_e (g, R)	Length (mm)	$p\beta c$ (MeV)	g^*	Remarks
	K-Ko_1		1.4		$1\,680^{+260}_{-530}$		21	190 ± 20	0.93 ± 0.02	Probable μ, but regarded as unsatisfactory
	K-Ko_2		0.3				1,8			
Stripped emulsions	K-Ko_3	12+2p	3	2	$1\,100 \pm 300$	$1\,110 \pm 160$ (*)	64	223 ± 22	0.96 ± 0.015	probable π could be μ
Stripped emulsions	K-Ko_5	11+12p	30	2	970 ± 210		58	167 ± 8	1.02 ± 0.02	probable π
Stripped emulsions	K-Ko_6	6+1p	4	1	880 ± 150	$1\,000 \pm 40$				
Stripped emulsions	K-Ko_7	16+2n	44	9	$1\,630 \pm 160$		34			
Stripped emulsions	K-Ko_8	23+9p	15	13						
Stripped emulsions							INTERACTION STAR			
Stripped emulsions	K^--Ko_4	11+4p	21	23	880 ± 250		2 short black tracks and one steep track at $g^* \leq 1.2$			

(*) Measured by von FRIESEN and KRISTIANSSON using the photoelectric method.

to be slightly lower than 1000 m_e. Five of the measured K-primaries are consistent with this mass. However K-Ko_7 seems definitely to be heavier. It was therefore carefully examined by scattering versus range in 6 different plates. The individual results vary from 1100 m_e to 2300 m_e, and the weighted mean value 1630 m_e is separated from the τ-mass group by roughly four standard deviations. If this result is affected by some distortion, the true mass value is higher, perhaps even superprotonic. Nevertheless a preliminary gap measurement gave $M_{\text{K-Ko}_7} = 990 \pm 110\ m_e$. The measured section of the track is however near the glass, and the single calibration proton is at a higher level in the emulsion. The mass values found in this way, therefore, may be somewhat wrong, but we do not believe more than by a factor of two. More work on this track is in progress.

The secondary particles from the K-decays have been, or will all be traced as far as possible and scanned for interactions. So far ~ 20 cm of secondary tracks have been examined with negative results. Scattering measurements have only been carried out on the secondaries of K-Ko_1, K-Ko_3 and K-Ko_5, which all provided long convenient tracks. The $p\beta$-value quoted for K-Ko_1 is however rather doubtful. It was deduced from the second differences in 100 μ cells, corrected for noise with 50 μ cells, but although the track is very flat the mean second difference increases with cell-size. By taking third differences one finds

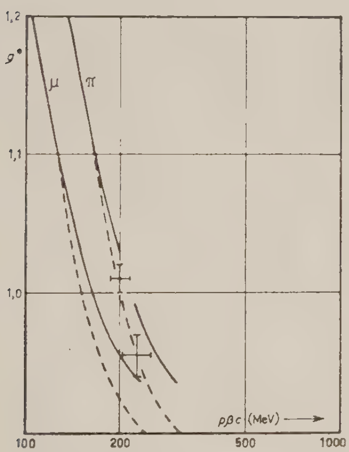

Fig. 1. - —— Bristol group, - - - - M. M. SHAPIRO.

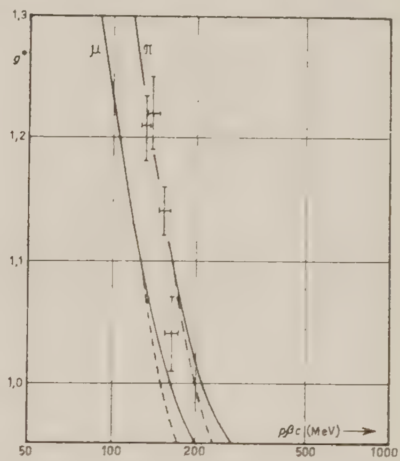

Fig. 2. - - - Bristol group, - - - - M. M. SHAPIRO.

the energy to be 25% higher, $p\beta c = 240$ MeV, as was reported at the Bagnères Conference. To explain this effect by a C-shaped distortion would require a distortion vector of about 4 mm. We therefore put no weight on the results, but note that very strange distortions do occur.

The secondaries K-Ko$_3$ and K-Ko$_5$ yield more consistent results. As we have not yet made a calibration curve of our own, we tried a tentative identification by comparing the measured blob density and $p\beta$-value with the well known curves of DANIEL *et al.* and SHAPIRO respectively. Although these curves from different laboratories are widely separated for high energies, they differ very little for values of g^* somewhat above the plateau.

From Fig. 1 it will be seen that the secondary of K-Ko$_3$ cannot be precisely identified, although it seems perhaps slightly more likely to be a π-meson than a μ. On the other hand the secondary of K-Ko$_5$ is slowed down sufficiently to give more reliable results. The scattering was measured in 6 different plates. and the $p\beta$ value was plotted versus the distance from the point of decay. The points were fitted by the best straight line with a slope corresponding to the expected energy loss. The blob density was measured in four plates and plotted by use of the interpolated $p\beta$-values. From Fig. 2 it appears that the evidence for this particle being a π is rather strong. The kinetic energy at the point of decay may be obtained by extrapolation rather accurately and is $E_{\pi} = 105 \pm 5$ MeV.

Fig. 3 shows the K$^-$-Ko$_4$ event. A heavy particle comes to rest and produces a capture star. The high energy track is rather steeply dipping, and leaves the stack after having traversed one more plate. The microphotograph shows also a part of the K-particle track where the residual range is about 4 mm. The track traverses 19 plates of the Copenhagen half of the stack 17. The Oslo group traced it through four plates to the parent star.

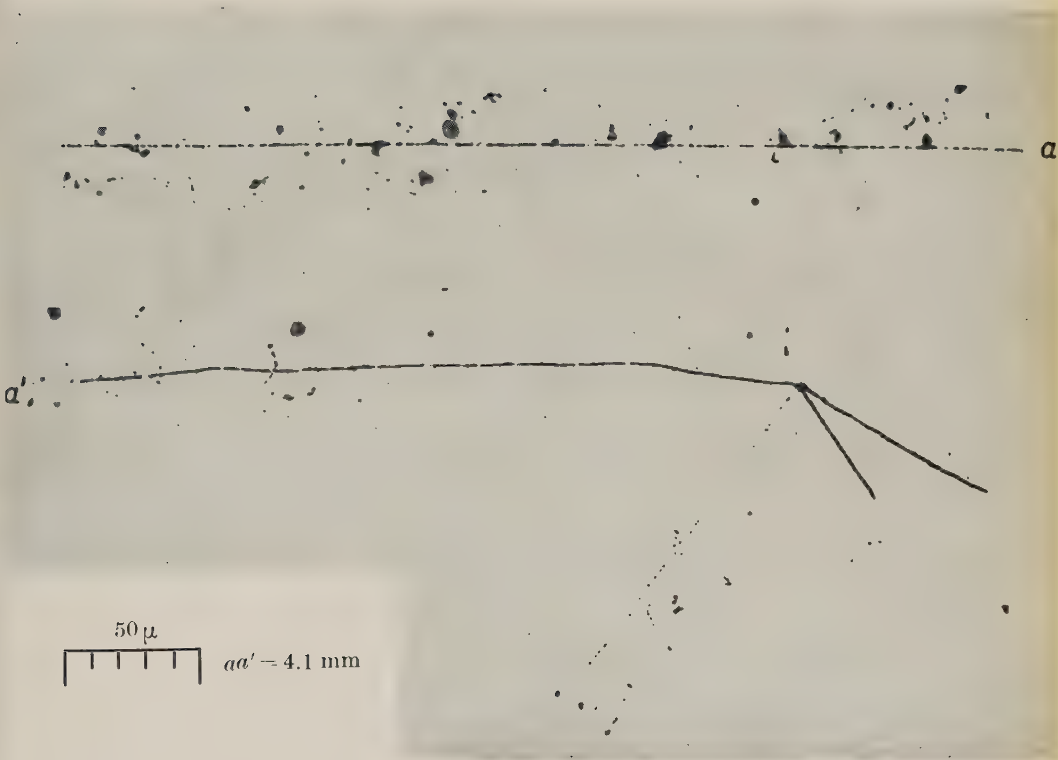

Fig. 3.

Mass and Decay of K-Particles.

A. BONETTI, R. LEVI SETTI and B. LOCATELLI

Istituto di Scienze Fisiche dell'Università - Milano
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

G. TOMASINI

Istituto di Fisica dell'Università - Genova

The investigation on K-mesons decaying at rest into a single charged secondary, carried out partly on plates and partly on a batch of stripped emulsions from the Sardinian Expedition 1953, has led to the identification of 7 examples of K-decay.

These events were found by normal scanning. For a portion of the scanned volume the data referring to the frequency of the events are listed in the following Table I.

TABLE I.

Particle	π^+	π^-	K	τ^+	$^{(\tau)}K^+_\pi$	σK	Y
No. of events	156	428	5	1	1	1	1

Scanned volume 16.5 cm³

The mass measurements on the primaries of K-mesons were made by the constant sagitta method, using the same cell set employed for calibration measurements on protons [1]. Cut-off procedure and noise elimination method were chosen according to the recommendations of the Varenna Summer School. Noise elimination was made between a basic cell set corresponding to the optimum cell size for π-mesons, and the double π-cell set.

In Table II are given the values of mass of the 7 K-particles; in the table are included 6 examples previously studied on glass plates [2]. The mass values given have been deduced from comparison with the average sagitta of the calibration protons, correction being made for the relativistic effect ($p\beta c \neq 2E$). In histogram of Fig. 1 is given the distribution in sagitta of the

Particle	Range (μ)	PRIMARY: Mass in m_e (constant sagitta)	PRIMARY: Mass in m_e (G, R)	Notes
K-GeMi$_1$	2 000	$1\,270 \pm 270$		glass plate
K-GeMi$_2$	5 260	$1\,030 \pm 165$	$1\,050 \pm 140$	»
K-GeMi$_3$	1 885	$1\,540 \pm 380$	$1\,170 \pm 270$	»
K-GeMi$_4$	1 470	$1\,360 \pm 340$		»
K-GeMi$_5$	640	$\sim 1\,000$		»
K-GeMi$_6$	3 400	$1\,010 \pm 200$	980 ± 290	»
K-GeMi$_7$	12 570	$1\,099 \pm 165$		»
K-GeMi$_8$	5 690 (1 plate)	$1\,380 \pm 270$		stripped emulsi
K-GeMi$_9$	19 240 (2 plates)	$1\,015 \pm 140$		»
K-GeMi$_{10}$	18 500 (17 plates)	$1\,025 \pm 160$		»
K-GeMi$_{11}$	18 330 (5 plates)	900 ± 125		»
K-GeMi$_{12}$	15 850 (5 plates)	850 ± 120		»
K-GeMi$_{13}$	9 400 (7 plates)	870 ± 165		»
K-GeMi$_{14}$	200	—		glass plate

Secondary			Star			
$p\beta$ (MeV/c)	g^*	Length (μ)	Type	Estim. energy	Angle of emission of K	Notes
50 ± 30	.94 ± .03	3 440				
	1·15 ± .1	450	30 + 8α	4 GeV/nucl.	106°	π^- emitted
08 ± 20	1.14 ± .03	20 85	34 + 6p	~ 10 GeV	166°	
00 ± 37	1.06 ± .04	2 500				
	~ 1	short				
		short				
	~ 1	short				
	~ 1	steep	4 + 0n			
53 ± 15	1.12 ± .012	51 000 measured: 30 000 in 9 plates	7 + 0p		29°	Star produced by a shower particle of a 24 + 11p star
55 ± 17	0.97 ± .012	4 000 measured: 24 000 in 11 plates				
90 ± 22	0.97 ± .013	> 53 000 measured: 14 000 in 5 plates	14 + 2p		6°	π^+ emitted
20 ± 12	1.2[illegible] ± .023	46 000 in 12 plates	4 + 2p		44°	
	~ 1	steep	16 + 0p		47°	
	~ 1	1 300				

K- and Y-particles decaying at rest and of the calibration protons. The distributions are very wide, with an indication of a peak around a sagitta corresponding to about 950 m_e, a peak at mass around 2 300 m_e given by the 4 Y-particles and a considerable intensity from 1 000 to 1 500 m_e. An interpretation of this spread is premature: it must be noted that, as we know that there is a population of particles decaying into a fast secondary with mass around 2 300 m_e, the probability that fluctuations from this population give mass values lower than the proton mass is rather high. Following DILWORTH *et al.* [3], we can estimate the relative probability P_K/P_Y of a given particle being a K-meson or an Y-particle, and from an estimate of the relative intensities of occurrence of the two events we find that in the region of mass around 1500 m_e the ratio becomes very near to unity.

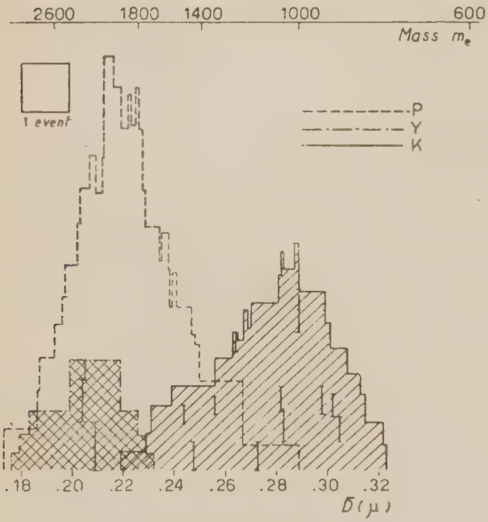

Fig. 1.

Also in Table II are given the data on the secondaries of the K-particles. In some cases the measurements have been made so far only on portions of the available secondary track. An identification of these particles with π^-- or μ-mesons has not been attempted at this stage, since the calibration curves of g^* versus $p\beta$ have not yet been made for this stack.

The errors on $p\beta$'s include the 8% uncertainty due to the scattering constant, as recommended by the Standardisation Commission (this Conference).

In the 14 cases, a total length of secondary track of 20 cm has been followed, without finding any visible nuclear interaction.

The stars in which these K-particles are born are all of relatively low energy, the parent star of $GeMi_8$ is of the type 4+0n, with a total visible energy release of the order of 200 MeV only.

The parent star of $GeMi_9$ is produced by a shower particle of a 24+11p star.

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Investigation on Grey Tracks of Particles Ejected from Energetic Nuclear Explosions.

R. R. DANIEL, A. KRISHNAN, S. MITRA and YASH PAL
Tata Institute of Fundamental Research - Bombay

Introduction.

Recent advances in the emulsion block detector technique make it possible to follow the tracks of charged particles with great residual ranges till they are brought to rest inside the stack of emulsions. In this way one can obtain the relative frequencies of stable and unstable particles of various masses ejected from nuclear disintegrations. The following results have been obtained in the first stage of a programme for following and investigating such grey tracks.

Selection of Tracks.

All tracks emanating from stars with one or more shower particles were followed provided that:

1) the track length per emulsion exceeded 1.0 mm (dip angle $\theta < 31^{\circ}$);
2) their grain density indicated that they were singly charged and had velocities in the interval $0.25 \leqslant v/c \leqslant 0.50$;
3) their potential range in the stack exceeded the range of a K-meson of the corresponding velocity ($2.7\ \text{mm} \leqslant R_{K} \leqslant 20\ \text{mm}$).

Results.

According to the above criteria of selection we have so far followed a total of 362 tracks. Whenever a track, which was traced from a star, was found

to stop inside the emulsion, its end was carefully scrutinised for any associated secondary track. In this manner we have found:

a) one example of a charged hyperon ($Y^{\pm}$-Bo_2) decaying in flight into a relativistic particle;

b) one example of a K-meson (K-Bo_6) coming to rest in the emulsion and disintegrating into a relativistic L-meson;

c) four cases in which a track after traversing a certain length suddenly undergoes a large angle deflection with significant increase in grain density, but no visible recoil;

d) three events in which a track after traversing some distance suddenly disappears in the sensitive region of the emulsion with no other associated track;

e) 31 cases of $\pi^{\pm}$-mesons.

Accurate measurements of grain density were made near the star end of the 105 tracks of particles which were brought to rest in the emulsion and had residual ranges $\gtrsim$ 10 mm. Except for one K-meson which was mentioned above and decayed into an L-meson, this sample contained no particles in the mass interval of 400-1400 m_e.

Details of the measurements made on events *a*), *b*) and *c*) are given below. Mass estimates made from measurements of grain density and scattering on the events described in *d*) indicate that they are quite possibly protons.

Event a) – (See Table I).

TABLE I. – *Particle* $Y^{\pm}$-Bo_2.

Parent Star	Type of decay	Primary		Secondary	
		Length (mm)	Mass in m_e (g, α)	Length (μ)	g^*
17 + 6p	in flight	8.0	2460 ± 500	572	1.25 ± 0.10

In this case it was not possible to trace the secondary particle beyond the first emulsion; it was assumed to be a π-meson and its momentum was estimated from its grain density. The Q-values were then calculated for the two decay schemes:

(1) $$\Lambda^{\pm} \to n + \pi^{\pm} + Q\,,$$

(2) $$\Lambda^{\pm} \to \Lambda^0 + \pi^{\pm} + Q\,.$$

They were 111 ± 25 MeV and 109 ± 25 MeV respectively, and the cor-

responding mass values for the primary particle are:

$$M_{\Lambda^\pm} = 2\,330 \pm 50 \text{ m}_e$$

and

$$M_{\Lambda^\pm} = 2\,670 \pm 50 \text{ m}_e$$

respectively.

Event b) – (See Table II).

TABLE II. – *Particle* K-Bo_6.

Parent Star	Primary		Secondary		
	Length (mm)	Mass in m_e (α, R)	Length (cm)	g^*	$p\beta$ (MeV/c)
21 ± 3p	5.0	1050^{+280}_{-200}	2.5	1.045 ± 0.02	240 ± 25

In this case the secondary particle was followed through 10 emulsions after which it leaves the stack. The method of third differences (to be reported in detail elsewhere) was used to eliminate the effects due to distortion in the scattering angle α_{100}. The corrected value for the $p\beta$ is 240 ± 25 MeV/c. Assuming that the particle is a π (μ) a $p\beta$ value of 240 MeV/c leads to a lower limit of $M_K > 1\,120$ m_e ($> 1\,040$ m_e) for the K-meson, while an error of one standard deviation reduces this limit to $M_K > 1\,040$ m_e (> 970 m_e).

Events c) – It is found that in all the four examples of large angle deflection without recoil described in *c)* the grain density after the bend is significantly higher than before the bend From the measurements made on the tracks before the bend they are identified as due to particles with masses near that of proton, after the bend the tracks could either be identified as due to protons or were consistent with proton tracks. Thus one could possybly attribute all of these events to nuclear scattering of protons. In fact the measurements made on two of these strongly support this interpretation. On the other hand mass values obtained for the other two examples, which permit quite accurate determinations of grain density and scattering seem to suggest that the particle before the bend is heavier than a proton and the events may be due to the decay of charged hyperons into a proton and some neutral particles. If we assume that they represent an alternative mode of the fairly well established decay scheme $\Lambda^\pm \to \pi^\pm + n$ (or Λ^0) $+ Q$, a likely interpretation of the events is the decay of a charged hyperon according to the scheme:

$$\Lambda^+ \to p + \pi^0 + Q\,. \tag{3}$$

Therefore these two events together with a third one found and measured by S. BISWAS and M. S. SWAMY of this laboratory have been analysed on the assumption that they represent such a decay process and the results are given below (Table III).

TABLE III.

Particle	Parent star	PRIMARY			SECONDARY		Q (MeV)
		Length (mm)	g before the bend	Mass (g, α)	Range (μ)	Mass in m_e (α, R)	
Y-Bo_3	24+4p	5.40	92 ± 4	2610^{+300}_{-250}	12450 ends	1950^{+600}_{-400}	129 ± 11
Y-Bo_4	17+12p	24.04	89 ± 4	2775 ± 185	824 ends	—	225 ± 25
Y-Bo_5	1+2n	4.22	104.5 ± 3	2470 ± 300	116 ends	—	212 ± 22

It is interesting to note that an event observed by BONETTI *et al.* [3] and another one by M. DANYSZ [6] in which the decay products are assumed to be protons give Q-values of 115 ± 3 MeV and 120^{+50}_{-30} MeV respectively. In addition an example similar to those given in Table III has been observed in Bristol (PERKINS, priv. comm.) and gives a Q-value of 245 MeV. All these cases have been analysed according to the decay scheme (3). Thus the total of six examples seem to fall in two groups of Q-values one around 120 MeV and the other 220 MeV. In order to confirm whether these do represent hyperon decays it is necessary to obtain either many more such events or events of the type observed by M. DANYSZ [6] where the grain density after the bend is lower than that before the bend.

Conclusion.

Since from this survey only one K-meson, one hyperon and two additional particles which may be hyperons have been found, it is difficult so far to draw any conclusion regarding their frequencies of production. They are consistent with the frequencies obtained in Bristol (2 K-mesons in about 600 grey tracks: PERKINS, priv. comm.).

In addition to the hyperon described above and another example reported from this laboratory earlier (LAL *et al.*, [1]), five charged hyperons which decay into a relativistic L-meson in flight or at rest, have been reported from other laboratories (BONETTI *et al.*, [3]; CECCARELLI and MERLIN, [4]; D. T.

KING *et al.*, [2]; C. CASTAGNOLI *et al.*, [5]). The mean mass obtained from direct mass measurements on these tracks weighted according to their track length is $2\,480 \pm 200\ m_e$. Assuming a Q-value of 120 MeV, the mass value of the hyperon for the two decay schemes (1) and (2) will be $2\,350\ m_e$ and and $2\,690\ m_e$ respectively. The experimental evidence at present is not yet sufficient to decide in favour of one or the other types of decay.

The two hyperons decaying into L-mesons which were observed in Bombay were found by following grey tracks and both decay in flight after traversing distances of 8.0 mm and 19 mm respectively. The direction of motion of these two particles was such that they would have come to rest inside the stack, if they had not decayed in flight. Therefore, we can say that their life-time is $\sim 10^{-10}$ s.

* * *

We have pleasure in thanking Prof. B. PETERS for his keen interest and guidance all through the course of this work.

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SUPPLEMENTO AL VOLUME XII, SERIE IX DEL NUOVO CIMENTO N. 2, 1954

Mass Measurements by the Ionization versus Scattering Method, on Fast Particles Emerging from Nuclear Disintegrations.

P. H. FOWLER and D. H. PERKINS

Reported by M. G. K. MENON

H. H. Wills Physical Laboratory - University of Bristol

Introduction.

Mass determinations are being carried out by combined measurements of multiple scattering and ionization on the tracks of fast charged particles emerging from nuclear disintegrations. The results described are provisional and must be treated with reserve. The experiments are an extension using « stripped » emulsions of the earlier work of DANIEL and PERKINS (*) on « single » emulsions.

Selection Criteria Employed.

1) Showers with 3 or more shower particles ($n_s \geqslant 3$) were examined.
2) Tracks with

   a) ionization at origin $1.1 < g^* < 2,2$;
   b) length per plate > 7 mm;
   c) total length in the stack > 4 cm;

were accepted.

Out of ~ 1000 showers, 250 such tracks were found; π-mesons were rejected by inspection: 130 tracks suitable for measurement were thus obtained.

Miminum length of track: 4 cm.

Maximum length observed: 14 cm.

Mean length of each track of the sample measured: 7 to 8 cm.

(*) R .R. DANIEL and D. H. PERKINS: *Proc. Roy. Soc.*, **221**, 351 (1954).

Scattering Measurements.

The tracks were scattered using a primary cell size of 100 μ. D-values were calculated in 100 μ, 200 μ, 300 μ cells. The tracks were classified in 3 groups:

a) Tracks with > 200 independent cells.
b) Tracks with 150-200 independent cells.
c) Tracks with < 150 independent cells.

Class *c*) were rejected.

The limited number of cells on tracks fulfilling the « minimum length criteria » might arise from the tracks being near cut edges, or processed edges where anomalous results might be obtained.

Results were obtained from one of the following:

a) Mean of $\bar{\alpha}_{2,1}$ and $\bar{\alpha}_{3,1}$
or *b*) Mean of $\bar{\alpha}_{3,1}$ and $\bar{\alpha}_{4,2}$
or *c*) $\bar{\alpha}_{3,1}$,

where $\alpha_{n,n+1}$ refers to the mean angle of multiple scattering obtained by noise elimination between cell sizes « n » and « $n+1$ ». The actual value accepted depends on the cell size on which values of $\bar{d} > 0.4$ are obtained. If the « estimated range » from the scattering is R, and the length used for scattering is L, and $R/L < 3$, then to take account of the variation of scattering with range along the track, a scaling procedure is employed and the finally quoted $\bar{\alpha}$ refers to the track centre.

Ionization Measurements.

For blob densities < 20 blobs/50 μ, the method of blob counting was employed. For blob densities $\geqslant 20$ blobs/50 μ both blob and gap counting were employed simultaneously.

It is known that:

$$B = \exp\,[-\,ga],$$

where B = blob density,
g = number of developable crystals,
a = crystal diameter + diffraction halo, etc..

The number, H, of gaps of size $> l$

$$H_{>l} = g \exp\,[-\,g(a+b)],$$

whence $B/H = \exp\,[gl]$ and $g = (1/l) \log\,(B/H)$.

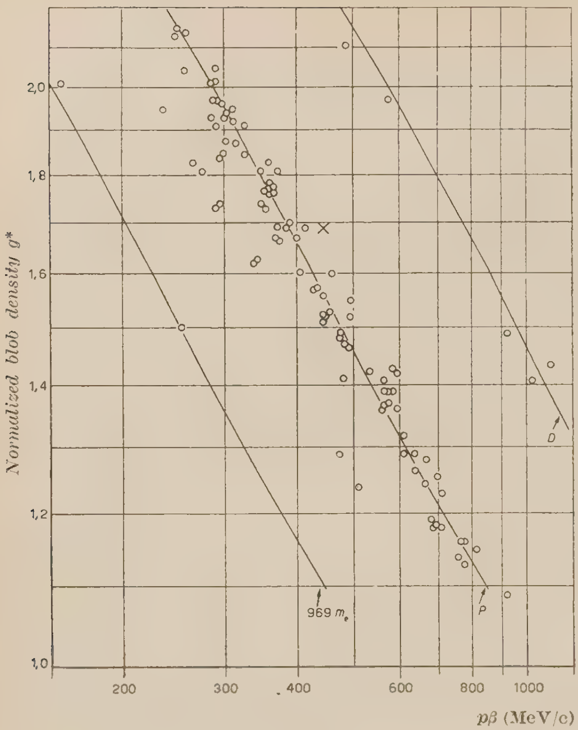

Fig. 1.

Thus by measuring both B and H it is possible to obtain g. About 100 gaps and 1000 blobs are counted in each of at least 4 sections on each track to obtain a final value.

Results.

The ionization versus scattering results are shown in Fig. 1, and the mass spectrum obtained from this in Fig. 2. The 130 tracks may be divided into the following mass groups:

1) 5 deuterons

2) 2 hyperons.

The measurements on the hyperons give:

(i) Mass $2\,330 \pm 100\ m_e$ on 75 mm;

(ii) Mass $2\,200 \pm 300\ m_e$ on 15 mm decaying in flight, with a $Q \sim 65 \pm 20$ MeV for the scheme $Y^{\pm} \rightarrow n + \pi^{\pm}$.

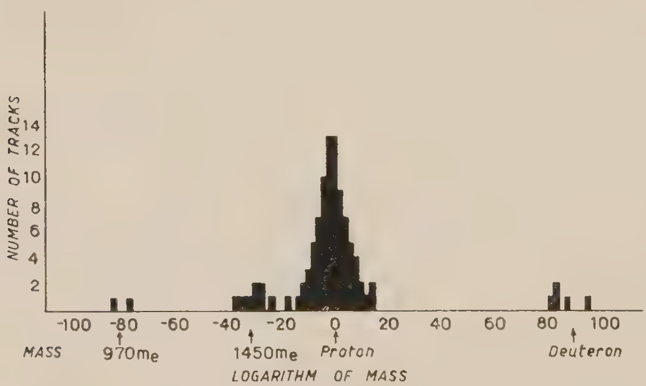

Fig. 2. Mass measurements on tracks of shower particles in stripped emulsions, using scattering and blob density. Minimum length of track 4 cm.

3) 112 protons.

4) 9 particles of mean mass $\sim 1\,450\ m_e$, with a total track length ~ 70 cm, time of flight $\sim 3 \cdot 10^{-9}$ s and one nuclear interaction.

5) 2 K-particles of mass $970 \pm 100\ m_e$ and $1\,030 \pm 50\ m_e$ respectively.

Conclusions.

The observations show the existence of a group at a mass value of $\sim 1\,450\ m_e$. It cannot be stated whether this is due to a different particle of mass less than that of a proton, or whether it arises from certain unknown and unrecognisable features inherent in the experimental method employed. It is not advisable, therefore, to draw far-reaching conclusions until results of greater statistical weight are available. It must be stressed, finally, that the results are as yet tentative and must be treated as such.

Some Speculations on the Nature of the K_μ-Particle.

U. HABER-SCHAIM

Physikalisches Institut der Universität - Bern

Recent observations of the Pic-du-Midi group [1] indicate the existence of a K-meson of mass $\sim 914\ m_e$ which undergoes a two particle decay, probably according to the scheme $K_\mu \to \mu + \nu$ with a life time of about $4\cdot 10^{-9}$ s.

It seems interesting to compare this process (to be characterized by the coupling constants e_4) with the decay of the pion (characterized by the constant e_3). By well known procedures [2] one obtains for the inverse of the life time of the pion

$$\frac{1}{\tau_\pi} = e_3^2 \cdot \frac{(m_\pi^2 - m_\mu^2)^2(m_\pi^2 + m_\mu^2)}{16\pi\hbar^2 m_\pi^5}\,. \tag{1}$$

Treating both mesons in the same way we find

$$\frac{\tau_\pi}{\tau_K} = \frac{e_4^2}{e_3^2}\,\frac{(m_K^2 - m_\mu^2)^2(m_K^2 + m_\mu^2)m_\pi^5}{(m_\pi^2 - m_\mu^2)^2(m_\pi^2 + m_\mu^2)m_K^5}\,. \tag{2}$$

Using the values $m_K = 0.5$, $m_\pi = 0.15$, $m_\mu = 0.114$ in nuclear mass units and $\tau_K = 2.56\cdot 10^{-8}$ s, we find

$$e_4 = 0.77 e_3\,.$$

Taking $e_4 = e_3$ we find $\tau_\pi = 2.24\cdot 10^{-9}$ s which is still in reasonable agreement with the observation.

This results looks slightly more significant if we look at the decay as a two step process

$$\pi \to N + N' \to \mu + \nu\,,$$

$$K \to N + N' \to \mu + \nu\,.$$

Using a very crude cut-off in momentum space in summing over the intermediate states [3], one finds (nearly) the correct life-time for the pion without introducing a new coupling constant (e_3). This holds also for the K_μ-decay, which seems to indicate that both pions and K_μ-mesons are coupled to the nucleon with the same strength.

It is tempting to ask why the K_μ-meson does not decay much faster into two pions via the virtual nucleon-antinucleon pair. One can argue that if the K_μ is a pseudoscalar particle it cannot decay into two pions. This still leaves the possibility of $K \rightarrow 3\pi$ or $K_\mu = \tau$. Indeed, the calculation performed along the same lines for the fourth order decay $K_\mu \rightarrow 3\pi$ using again the same cut-off gives a life-time of about 10^{-14} s. If both modes of decay are observed with comparable frequency the respective life times should not vary by more than a factor of about ten. It should be noted, however, that a similar calculation for the decay of $\pi^0 \rightarrow 2\gamma$ also gave two short a life time by a factor of 10^3.

If one is optimistic, one may hope that when we know how to calculate correctly the life-time of the π^0, the life-time of the τ will also be accessable to calculation, and will turn out to be $\sim 10^{-9}$ s. If one is pessimistic, one has to look for a different explanation of the K_μ decay, since their strong coupling to the nucleons is also indicated by their production rate, which is comparable to that of other heavy mesons which do decay into pions.

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Résultats sur les mésons K⁺.

T. F. Hoang, L. Jauneau, G. Kayas, A. Orkin-Lecourtois,
L. Leprince Ringuet, D. Morellet, G. Tariel et J. Trembley
Laboratoire de Physique de l'École Polytechnique - Paris

Les résultats sont résumés dans le Tableau I. Ils sont relatifs à un dépouillement systématique de 24 cm³ d'émulsion exposée en Sardaigne correspondant a 1020 $\pi^{\pm}$, 17 K^{+}, 2 τ^{+} et 1 $^{(?)}K_{\pi}$ (anciennement τ'). Les plaques utilisées présentent une densité minima assez faible: 18 grains/100 μ. Il a été le plus souvent impossible de mesurer les secondaires sauf s'ils présentaient un parcours > 5000 μ dans la première plaque.

Nous avons choisi parmi les primaires les plus favorables et nous avons essayé d'appliquer à ceux-ci autant de méthodes de mesure que possible.

Les 4 secondaires mesurés ont des $p\beta c$ groupés autour de 195 MeV. Ceci peut-être une simple fluctuation ou bien indiquer que Ep_{13}, Ep_{17}, Ep_{19} et Ep_{20} sont du type K_{μ}. Malheureusement cette hypothèse ne peut être verifiée sur les 4 masses des primaires. Les mesures d'ionisation sur Ep_{18} indiquent pourtant que cet évènement est compatible avec le K_{μ}.

Les étoiles de production des 17 mesons lourds ne présentent aucun caractère bien particulier hormi l'étoile du Ep_{9}. Celle-ci est en effet du type 2+0p et contient 1 π^{-} lent donnant une étoile σ, une particule dont l'ionisation et le $p\beta$ sont incompatibles avec un proton et qui est probablement un π et le meson Ep_{9}. Cette étoile peut trouver, peut-être, une explication simple.

Les masses des primaires ont été mesurées: *a*) par une méthode de comptage integral de gaps sans coupure (Kayas); *b*) une méthode de scattering à flèche constante (étalonnée sur 18 π et 19 p) (A. Orkin-Lecourtois); *c*) une méthode de comptage différentiel de grain (Hoang); *d*) une méthode photométrique a fente fine (étalonnée sur 35 p) (Morellet).

La particule primaire Ep_{11} (notée aussi S_{11}) semble permettre une déduction intéressante. Il est difficile de combiner directement les résultats des méthodes

Primaire				Secondaire			Étoile	
Particule	Parcours Total (μ)	Masse en m_e (flêche constante)	Masse en m_e (ionization-parcours)	$p\beta$ (MeV/c)	Longueur dans le paquet (μ)	Notes	Type	Notes
K-Ep_8	9 500	920 ± 155	862 ± 60 (+)			$\sim I_0$	28 + 6p	
K-Ep_9	2 050	1 210 ± 390	950 ± 250 (+)				2 + 0p	cette étoile contient seulement 1 $\pi^- \to \sigma$. 1 $\pi^\pm$ et la particule K
K-Ep_{10}	8 700	1 100 ± 198	990 ± 150 (+) 921 ± 60 (*)				11 + 2n	
K-Ep_{11}	2 700	1 083 ± 294	950 ± 140 (+)				29 + 11p	
K-Ep_{12}	37 400	805 ± 177	960 ± 190 (+)				13 + 5p	
K-Ep_{13}	> 19 250	1 413 ± 316	881 ± 80 (*) 960 ± 130 (+)	200 ± 20	7 175			origine extérieure au paquet
K-Ep_{14} K $\to \mu \to e$	> 9 630	934 ± 165	1 240 ± 90 (*) 1 300 ± 175 (+) 1 050 ± 90 (×)	$E - 33.3$ (MeV)	23 205	$\mu \to e$		origine mal definie qui peut être un scattering nucléaire du méson K
K-Ep_{15}	4 660	1 005 ± 320					21 + 0p	
K-Ep_{16}	27 800	1 075 ± 190					8 + 2p	
K-Ep_{17}	14 000			180 ± 10	> 49 000			
K-Ep_{18}	10 300							
K-Ep_{19}	585	1 195 ± 263		194 ± 34	> 20 000		4 + 0n	
K-Ep_{20}	18 500			195 ± 30	> 5 000			
K-Ep_{21}	> 40 000	1 120 ± 160						origine extérieure au paquet
K-Ep_{22}	29 500						7 + 0n	
K-Ep_{23}	18 400						19 + 1p	

(*) Mesure phothometrique - parcours. (+) Comptage de lacunes - parcours. (×) Comptage de grains - parcours.

a, *b*, *c*, *d*. Si toutefois on le fait pour cette particule, on obtient

a) gaps	$1\,300 \pm 175\ m_e$		Valeur ponderée
b) scattering	934 ± 165 »		par rapport aux écarts types
c) grains	$1\,050 \pm 90$ »		$\overline{M}_{Ep_{14}} = 1165 \pm 65\ m_e$.
d) photom.	$1\,240 \pm 90$ »		

Si on se borne a combiner les méthodes d'ionisation, on obtient une moyenne d'environ $1\,200\ m_e$.

Une conclusion plus nette semble apparaître avec les résultats de la méthode des gaps et surtout avec ceux de la méthode photométrique car celle-ci conduit à des erreurs (standard-déviation) plus petites.

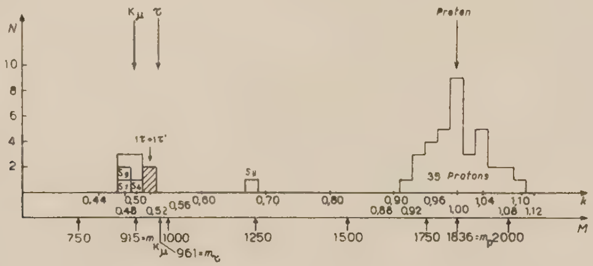

Fig. 1.

Serie 102 (non pelées)	K-Ep$_2$ $902 \pm 15\ m_e$ 5 000 μ	K-Ep$_8$ $862 \pm 60\ m_e$ 5000 μ	Sardaigne $\Delta M/N = 6\%$
		K-Ep$_{10}$ 921 ± 60 » »	σ_{et} = 14 m
	K-Ep$_3$ 930 ± 80 » 6 000 »	τ-Ep$_1$ 920 ± 95 » »	
		K-Ep$_{13}$ 881 ± 80 » »	
	K-Ep$_4$ 910 ± 70 » 9 000 »	K-Ep$_{14}$ 1240 ± 90 » »	
		$^{(\tau)}K_\pi$-Ep$_1$ 941 ± 66 » »	

Moyenne totale pour K $901 \pm 25\ m_e$ 6 particules

Moyenne totale pour p $1849 \pm 14\ m_e$ 35 particules

La fig. 1 montre la répartition des masses de 6 meson K^+, 2 τ et 35 protons ainsi que le méson K-Ep$_{14}$. Il ressort de cette figure que $M_{Ep_{14}}$ est une masse nettement disjointe de la masse 900-950 m_e par la méthode photométrique.

A Decay Curve of K-Particles.

L. MEZZETTI (*) and J. W. KEUFFEL (+)
Physical Laboratory, Princeton University - Princeton, N. J.

Time lags between the pulse from a directional Čerenkov counter and the pulse from a liquid scintillation counter have been measured with the apparatus shown in Fig. 1. The apparatus was triggered by penetrating events

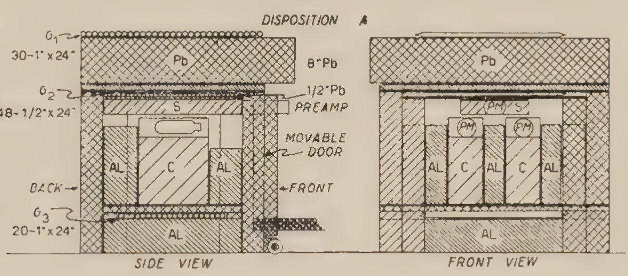

Fig. 1.

produced in the top Pb layer by cosmic rays. The Čerenkov counter has a high efficiency for detection of upward going relativistic particles, a very low efficiency for downward going particles and zero efficiency for particles with kinetic energy $E < 0.52\ Mc^2$. These two properties of the Čerenkov counter are essential in order to discriminate against unwanted types of events. Auxiliary information is provided by Geiger counters, through an 80 channel hodoscope.

The delay distribution obtained for a group of events of low and intermediate multiplicity is shown in Fig. 2 (full-line) and compared with a «timing error» distribution (dashed line) obtained with the same arrangement but for the Čerenkov counter, which was turned upside down, to make it sensitive to

(*) On leave of absence from the University of Rome, Italy.
(+) Now at the University of Utah, Salt Lake City, Utah.

downwards going particles. High multiplicity events have been singled out to avoid a too great broadening of the « zero lag » peak, due mainly to rise time effects in the photomultipliers, as was shown by a careful study of their behaviour.

The peak at zero delay is interpreted as due to the residual efficiency of the Čerenkov counter for downward going particles. The points at times greater than ~ 12 mμs appear to follow a single exponential; if the data are analyzed on this basis by the method of Peierls the mean life turns out to be 8.7 ± 1.0 mμs and the rate of such events, extrapolated to zero delay, 3.5 h^{-1}.

A number of auxiliary experiments have been performed in order to check various types of spurius events which could possibly give rise to delayed pulses in our apparatus. None of them appears to contribute appreciably to the exponential « tail »; neither, in our opinion, can it be instrumental. Our interpretation, therefore, is that in nuclear events, produced in the top Pb layer, unstable particles are produced, which decay at rest in or in the vicinity of the Čerenkov counter with the emission of an ionizing relativistic secondary; this secondary is detected when it happens to cross the Čerenkov counter in the upward direction (within a certain favorable cone). If this interpretation is correct, the mean life obtained is in agreement with previous estimates based on cloud chamber observations of decays of mesons heavier than π's (V- and S-particles) [1, 2]. In this connection we wish to emphasize that our detector is absolutely insensitive to the $\pi \to \mu$ decay and also to the $\tau \to 3\pi^{\pm}$ decay (because of the Čerenkov energy threshold mentioned before).

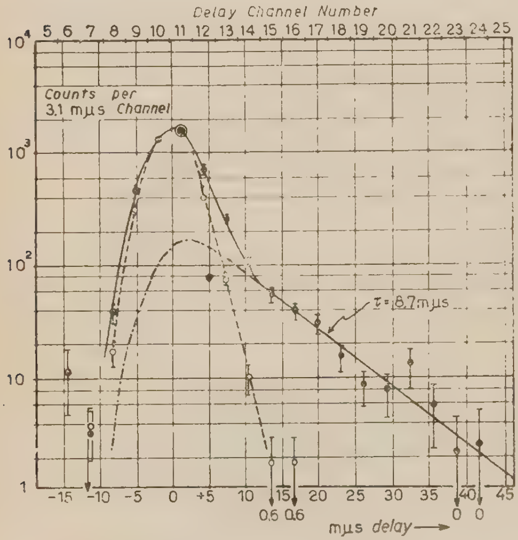

Fig. 2.

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On the Mass of Fast K-Particles.

S. ROSENDORF, R. STAHL and G. YEKUTIELI
The Weizmann Institute of Science - Rehovoth, Israel

The experiment was carried out in a batch of Ilford G5 plates, 400 μ in thickness, exposed to the cosmic radiation at 90 000 ft for 6 hours (*). Measurements of multiple scattering and grain-density were made on all secondary shower particles ejected from stars with $n_s \geqslant 1$. Out of these tracks we chose for further analysis those which *a*) had blob-density between 1.05 and 1.50 plateau value, and *b*) for which the mass associated with them was known with a probable error of less than 20%. In this way 55 tracks were selected (their length in the emulsion was between 5 and 34 mm). 20 of the selected tracks were identified as π-mesons and we shall not consider them here. The masses, with the probable errors, of the 35 particles are shown in Fig. 1. We shall first test the assumption that all the 35 particles are protons. Now, if m is the measured mass of one of these particles and S is its standard deviation, we shall find a value λ_p such that $m \pm \lambda_p S$ will just cover the mass of a proton. Assuming a normal distribution for both $\bar{\alpha}$ and the blob-density g^* we can find in published tables [1], the probability P % corresponding to the value λ_p. The statistical meaning of this procedure is that if we measure the mass of a large group of protons, then in P % of the cases the measured value $m \pm \lambda_p S$ will cover the mass of a proton. Applying this procedure to each of the 35

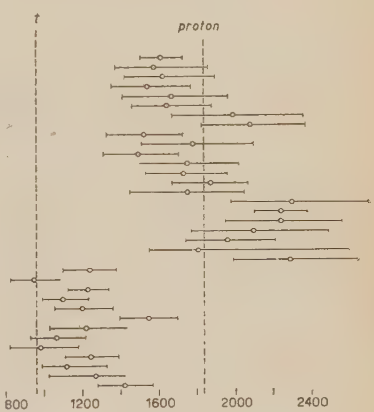

Fig. 1.

(*) We are indebted to Dr. M. M. SHAPIRO of the U.S. Naval Research Laboratory (Washington, D.C.) for these plates.

particles, we find that only in 22 cases, will the estimated value of the mass $m \pm \lambda_p S$ cover the proton mass value with a probability level higher than 10%. Therefore we find, with the help of the χ^2 test, that the assumption that all the 35 tracks are protons is below the 0.1% level and should be rejected. Assuming that all the 22 particles that cover the proton mass value with a probability level higher than 10% are protons, we find an average value of 1780 ± 62 m_e for their mass. The average mass of the other 13 particles is 1220 ± 50 m_e. Next we consider the possibility that the 35 particles are made up of three groups of particles: protons with mass of 1 837 m_e, and two groups of K-particles, one with mass 960 m_e, similar to the mass found for stopped K-particles in emulsions and in cloud chamber experiments, and another with mass of about 1 450 m_e (evidence for a K-particle with mass of 1 450 m_e has been given recently by FOWLER and PERKINS in Bristol [2]). In Table I the probability levels that the different tracks were

TABLE I. – K-*Particles.*

No.	Mass (m_e)	Probability level for mass		
		1 837	1 450	960
2	1520 (14)	10	95	5
4	1270 (13)	3	50	20
17	1120 (19)	2	40	60
23	1245 (12)	1	42	35
27	983 (21)	1	30	95
43	1060 (15)	1	20	95
47	1550 (10)	2	65	1
63	1215 (18)	6	50	50
70	1200 (14)	1	30	32
71	1100 (12)	1	16	45
78	1260 (11)	1	25	18
80	1495 (14)	25	95	10
87	1230 (9)	1	25	10
90	950 (15)	1	12	95
95	1525 (13)	32	95	7
101	1540 (15)	40	95	8
103	1575 (15)	42	93	8

The numbers in brackets are probable errors in %.

protons, K-particles of 1450 m_e or K-particles of 960 m_e are given. 18 particles which were most probably protons are not included in this table. With the help of Table I, we find that the most probable division of these particles into three groups is as follows: 18 protons with an average mass of 1820 ± 65 m_e;

12 K-particles with an average mass of 1310 ± 55 m_e, and 5 K-particles with an average mass of 1060 ± 77 m_e.

It is seen from Table I that only 3 particles will not cover either the proton or the K-particle of mass 960 m_e, with a probability level higher than 10%. Now, in a group of 35 particles and with a probability level of 10%, it is very likely (more than 95%), that in 3 cases the measured values will not cover either the proton or the 960 m_e mass values. Therefore, the division into three groups of different masses is not significant, and our own data is consistent with one of the following assumptions:

1) the 35 particles consist of two mass groups: 22 protons with average mass of 1780 ± 62 m_e, and 13 K-particles with average mass of $1220 \pm 50 m_e$,

or

2) they consists of three mass groups: 18 protons with average mass of 1820 ± 65 m_e; 12 K-particles with average mass of 1310 ± 55 m_e, and 5 K-particles with average mass of 1600 ± 77 m_e.

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The Production of Heavy Mesons and Hyperons in Nuclear Disintegrations.

C. Dahanayake, P. E. Francois, Y. Fujimoto, P. Iredale, C. J. Waddington, and M. Yasin.

H. H. Wills Physical Laboratory - University of Bristol

This is a preliminary report on an investigation being undertaken in Bristol.

The object of this investigation is to make a systematic study of all the particles with $\sim 0.2 < \beta < 0.55$ emitted from high energy nuclear disintegrations, with particular reference to the production rates and energy spectra of the heavy mesons and hyperons.

We are using two stacks of stripped emulsions. One, HA 54, was flown in England last spring for three hours at an average altitude of about 80 000 ft while the other, S 35, was flown in Sardinia for eight hours at over 80 000 ft. The plates of these stacks have been scanned for stars having two or more secondary shower particles, ($N_s \geqslant 2$), and from stars of this type we have selected tracks having grain densities in excess of twice minimum, and satisfying certain geometrical criteria which are varied depending on the position of the plate in the stack, so as to ensure that the stack length available is appreciable.

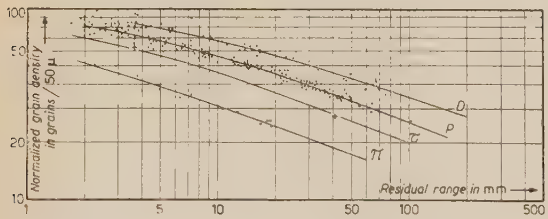

Fig. 1.

On each track selected we have measured the grain density (counting 600 grains) at a convenient point near the star, and then following it until it has either left the stack, interacted, or come to rest. When the track comes to rest we are able to plot the grain density against the residual range, obtaining a plot similar to that shown in Fig. 1.

This is a typical plot obtained by one observer, and is in fact rather worse

than those that we obtain now, as it was made before the plates were properly normalised. Each observer makes his own plot, due to the difficulty experienced in making different observers' grain counting conventions conform.

From these observations we are able to obtain a mass spectrum.

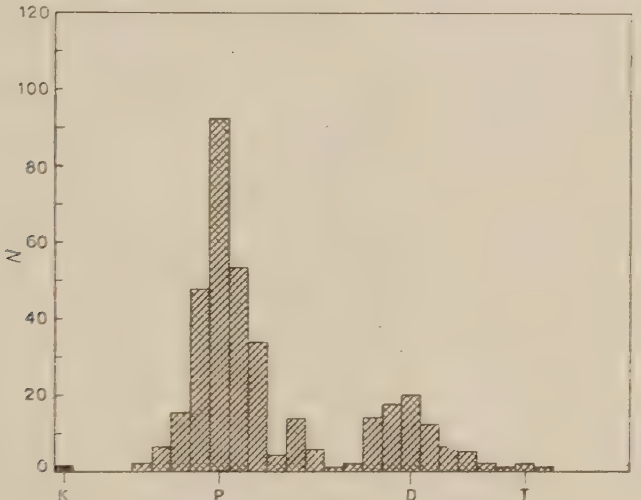

Fig. 2.

The one shown in Fig. 2 is typical of the resolution that we obtain for normalised plates. Particles of mass 1 000 m_e are well resolved from the protons, so that we are able to identify them independently from any secondary effects occurring at the end of their range. In addition we are able to increase the precision of mass measurement on any particle of particular interest by making grain counts at different points along the track, and thus obtaining a number of independent mass values. This is of particular importance if we wish to investigate whether there are any particles with masses unresolved from the protons, such as the particles of mass 1 450 m_e reported by FOWLER and PERKINS, or the hyperons. We should have a good chance of observing particles of mass 1 450 m_e, but in the case of the hyperons we are dependent on secondary effects for our identification.

We have to date obtained the results listed in the following Table I.

TABLE I.

Plate	Area (cm²)	Stars	Tracks	p	d	t	α	U	π	K	Y
HA 54	700	2 127	1 782	1 049	325	46	39	260	58^{+12}_{-46}	5	0
S 35	200	613	524	276	134		13	80	17^{+3}_{-14}	3	1

The U column represents unidentified particles. These are particles which either leave the stack without having a sufficient change in grain density to enable them to be identified, or which interact before travelling far in the stack. We therefore expect a high proportion of d's and t's among this group.

Of the 8 K-particles we have, 7 come to rest, and decay with a minimum secondary ($K\text{-}Br_{25}$, $K\text{-}Br_{26}$, $K\text{-}Br_{32}$, $K\text{-}Br_{33}$, $K\text{-}Br_{35}$, $K\text{-}Br_{38}$ and $K\text{-}Br_{41}$), while one leaves the stack. Details of these K's will be published later (*).

It is of particular interest that the hyperon is emitted from a star which also emits one of our K-particles. An analysis of this event in terms of a reaction:

$$x + N \to Y + K ,$$

gives for the mass of x $300 < m_x < 700\ m_e$, so this event is not inconsistent with the process:

$$\pi + N \to Y + K$$

reported from Brookhaven.

While it is still too early to draw any conclusions from our limited statistics, we would like to point out the future possibilities of the method. Our detection of K-mesons appears to be extremely efficient with the conditions that we set. The only real possibility we have of missing any is if they interact in flight before travelling more than a few mm from the star. It should therefore be possible to obtain the production ratios of τ-mesons and K-mesons, and if we are able to correlate our results with those of the Paris group, to make a statistical separation between the K's and the K_μ's we observe. In addition, by working via the π-meson production ratios, we will be able to compare our results on charged K-mesons with those obtained by FRIEDLANDER *et al.* on the production of Λ^0-particles. However, the position is not so favourable when we consider the position of hyperons; here we are dependent on the secondary effects, and these may not always be recognisable. As an example, in the decay:

$$Y \to p + \pi^0$$

if the proton is emitted backward in the center of mass system, so that the change in grain density is an increase, instead of a decrease, then we will not in general be able to distinguish this from the inelastic scattering of a proton. This bias must be taken into account when we consider the results.

(*) See in this issue, pag. 436, 437.

Remarks on Heavy Mesons.

M. M. Lévy

École Normale Supérieure - Paris

R. E. Marshak

Faculté des Sciences - Paris (*)

It is perhaps appropriate to take advantage of the opportunity afforded by this Padua Conference on Elementary Particles to present some qualitative conjecture concerning the structure of the heavy mesons, in particular the θ and τ varieties which decay into two and three π-mesons respectively. We have as yet no quantitative results to report, but in a field as confused as that of elementary particle physics qualitative remarks may possess some value, especially if they have experimentally verifiable consequences.

We take as our starting point the interesting experimental fact that while the masses of the τ and θ-particles are approximately equal (1), they cannot be identified as different forms of the same elementar particle (2). We wish to show that it may be possible to explain this fact plus the longevity of both the τ and θ-particles without any additional hypotheses other than those necessary to explain the large production cross-section and the long-lived decay

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(*) Guggenheim Fellow on leave from the University of Rochester for the academic year 1953-54.

(1) This is certainly true of $\tau^{\pm}$ and θ^0 for which the recent mass determinations are the same within experimental error (965 ± 2 for $\tau^{\pm}$, 965 ± 20 for θ^0). The evidence for $\theta^{\pm}$ is contained in the work of the Bristol and other emulsion groups and the observation of γ-rays associated with stopped heavy mesons in cloud chambers. The existence of τ^0 is least well established although indirect support is provided by the recent observation of the alternative mode of decay of $\tau^{\pm}$. For details, see the *Proc. Rochester Conf.*, 1954, and also this issue, Sez. II, pag. 181. For the purposes of our discussion, we assume that $\tau^{\pm}$, τ^0, $\theta^{\pm}$, θ^0 all exist.

(2) Preliminary experimental evidence on the π-meson spectra arising from τ-meson decay support the assignment of spin 0 to the τ-particle (cf. R. H. Dalitz: *Proc., Rochester Confer.*, 1954); the θ-particle must then be different.

of the hyperons. In our discussion, we shall make full use of PAIS' recent ideas ([3]) which assign to pions and nucleons a new quantum number, that of « ω parity »; however, much of our argument could be retained even if some formulation other than that of PAIS is necessary to explain the hyperons ([4]).

According to PAIS, we must assign even ω parity to the pion π_0 (π_0^0 will denote the neutral pion and $\pi_0^{\pm}$ the charged pions) and to the nucleon N_0 (N_0^0 will denote the neutron, N_0^+ the proton) and odd ω parity to the first excited states of the pion and nucleon classes, π_1 and N_1, respectively. The strong interactions require the conservation of ω parity and therefore exist only among the combinations ($\pi_0N_0N_0$), ($\pi_0N_1N_1$) and ($\pi_1N_0N_1$); the weak interactions are presumed to exist among the other combinations. Furthermore, in Pais' theory, fast γ-ray transitions can only take place between particles possessing the same ω parity.

Now the interaction between two nucleons is presumably due to the pseudoscalar π_0 field and, in analogy, we would expect a normal nuclear force between two N_1's and a nuclear force of comparable strength but much shorter range ([5]) (since the mass of π_1 is taken to be larger than the mass of both the τ and θ-mesons - see below) between N_0 and N_1. On the other hand, we would expect that the « exchange » forces between N_0 and N_0 ([6]), N_1 and N_1 ([6]), N_0 and N_1 and N_0 and N_1 would be much stronger than the ordinary nuclear forces ([7]) and, under favorable circumstances, could lead to bound systems with very large binding energies ([8]). If we assume what is, after all, the crucial point in the entire discussion ([9]), namely that such highly bound states

([3]) A. PAIS; *Physica*, **19**, 869 (1953); it should be emphasized that Pais' explanation of the copious production and longevity of the hyperons requires the existence of excited states of pions (as well as nucleons) of odd ω parity.

([4]) For example, if the long lifetime of the hyperons is due to the metastability of a high angular momentum state of the pion-nucleon system (cfr. R. ARNOWITT and S. DESER: *Phys. Rev.*, **92**, 1061 (1953) and B. P. NIGAM: *Phys. Rev.*, **93**, 914 (1954)).

([5]) The shorter range force between N_0 and N_1 could explain the apparently weaker binding which is observed in the unstable heavy fragments (cf. *Proc. Rochester Confer.*, 1954, and also in this issue, pag. 466.

([6]) $\overline{N}_0$ and N_1 denote the antiparticles to N_0 and N_1 respectively.

([7]) With pseudoscalar coupling this can be understood in virtue of the fact that the γ_5 operator favors pair production and annihilation; besides, the energy denominator corresponding to the intermediate state following the virtual annihilation of a particle (N_0 or N_1) and an antiparticle (N_0 or N_1) is much larger than in the case of two particles interacting.

([8]) This is to be contrasted with the theory of FERMI and YANG (*Phys. Rev.*, **76**, 1739 (1949)) which attempted to explain the existence of the π_0 particles (i.e. ordinary pions) in terms of bound systems of nucleon-antinucleon pairs.

([9]) The calculation intended to demonstrate the existence of these bound states requires the solution of a Salpeter-Bethe type of equation beset by special renormalization difficulties and has not yet been completed.

exist, then some rather interesting consequences follow. Both bound systems $(N_0 N_0)$ and $(N_1 \bar{N}_1)$ will decay rapidly into two or three π_0's [10] as long as the mass of each system is greater than 3μ (μ is the mass of π_0); on the other hand, the bound systems $(N_0 N_1)$ and $(N_0 N_1)$ will decay slowly even if their masses are greater than 3μ since they possess odd ω parity. This is true provided however that their masses are smaller than that of π_1 so that fast γ-ray emission can not take place. We propose to identify the τ and θ-mesons with the ${}^1S_0$ and ${}^3P_0$ states [11] of the bound systems (N_0N_1) and/or (N_0N_1) respectively where, in accordance with the above, the exchange force associated with the π_1 field is responsible for most of the binding; a small splitting between the ${}^1S_0$ and ${}^1P_0$ states could result from the ordinary nuclear force terms. This identification would imply that the τ and θ-mesons are pseudoscalar and scalar particles respectively, that they both possess odd ω parity and that the π_1-meson can readily decay into them with comparable probabilities (via two γ emission). Two γ-ray emission is possible between τ and θ but will be sufficiently inhibited if the mass difference is sufficiently small.

We can now predict what the production and absorption mechanism should be for the τ and θ-mesons. In both pion-nucleon and nucleon-nucleon collisions, the production of either a τ or θ-meson would mainly be a two-step process, viz. in a pion-nucleon collision, one would obtain: $\pi_0 + N_0 \to N_1 + \pi_1$, $\pi_1 \to \tau + 2\gamma$ or $\pi_1 \to \theta + 2\gamma$ and in a nucleon-nucleon collision the first step would be: $N_0 + N_0 \to N_0 + N_1 + \pi_1$ and the second step would be the same as above [12]. These production mechanisms are not in disagreement with the meager experiments performed thus far; as a matter of fact, the recent Brookhaven experiment in connection with negative pion-proton collisions [13] contains features which are in surprising accord with the above mechanism:

(10) The existence of strongly bound systems of nucleon-antinucleon pairs decaying rapidly into pions would help explain the remarkable failure thus far to observe antinucleons; the severe competition from those bound systems would effectively raise the energy threshold for the production of free antinucleons.

(11) Charge conjugation does not allow the θ^0 and τ^0-particles to exist in the states which are forbidden by the Pauli principle for two identical particles (L. MICHEL: private communication).

(12) There is also the possibility of direct production through (N_1, N_1) pair creation: for example, in a pion-nucleon collision: $\pi_0 + N_0 \to N_1 + N_1 + N_0 \to N_1 + (\theta \text{ or } \tau)$ and in a nucleon-nucleon collision: $N_0 + N_0 \to N_0 + N_0 + \pi_0 \to N_0 + N_0 + N_1 + N_1 \to N_0 + N_1 + (\theta \text{ or } \tau)$. Since, however, there will be a strong tendency for the (N_1, N_1) pair to be emitted in a highly bound state, the probability of having it dissociate in the intermediate state to form a θ or τ-particle will presumably be appreciably smaller. The same argument would favor the inelastic (rather than the elastic) θ or τ-meson scattering by nucleons (see below).

(13) W. B. FOWLER, R. P. SHUTT, A. M. THORNDIKE and W. L. WHITTEMORE: *Phys. Rev.*, **91**, 1287 (1953); **93**, 861 (1954).

e.g. in the two cases where the mass of the neutral heavy meson accompanying the neutral hyperon was measured reasonably well, it turned out to be 1300 electron masses, which is appreciably higher than the mass of the τ or θ-meson. In the case where θ^0 was found to be associated with N_1^0 (i.e. Λ^0), it was difficult to check the absence of energy-momentum conservation which should, on our theory, be present. According to our hypothesis, τ^0 should accompany N_1^0 with comparable frequency to that of θ^0, a prediction which can only be checked by appreciable improvement in the statistics. The smaller number of charged hyperons observed in the Brookhaven experiment compared to N_1^0 can, perhaps, be explained by the larger Q-value of the charged hyperons ([14]), thereby increasing the threshold energy.

The absorption (and scattering) mechanism for the τ and θ-mesons are different, depending on the kinetic energies involved. If the τ^- and θ^- are absorbed from the orbits of the corresponding mesic atoms, then the only fast reaction which can take place yields $N_1+\pi_0$, unless the masses of τ^0 and θ^0 are smaller than the masses of τ^- and θ^- respectively, in which case reactions corresponding to pion charge exchange reactions can take place. At any rate, an explanation would thus be provided for the rare occurrence of visible stars associated with τ^- and θ^- absorptions ([15]) since the threshold argument for charged hyperons would hold with even greater force than for the Brookhaven experiment (see above). At positive kinetic energies, the elastic scattering of the τ and θ-mesons can take place and at energies greater than the hypothesized mass difference between π_1 and the τ and θ-mesons, the fast inelastic reactions leading to $N_0+\pi_1$, $\pi_1\to\tau+2\gamma$ or $\pi_1\to\theta+2\gamma$ can occur.

In conclusion, it is to be hoped that some crucial experiments will be performed in the near future to decide whether the speculative remarks presented above ([16]) possess any merit and deserve further elaboration.

([14]) It should be stated that one of the most troublesome points in connection with the N_1 particles is the appreciably larger Q-value for N_1^+ (and N_1^-) compared to N_1^0; if charge independence holds, it is difficult to explain this difference other than as an electromagnetic effect.

([15]) See *Proc. Bagnères Confer.*, 1953.

([16]) Chiefly in footnotes, it appears.

Negative K-Mesons (*).

M. BALDO, M. CECCARELLI, M. GRILLI and G. T. ZORN
Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

During the scanning of 51.3 cm³ of stripped emulsion exposed at high altitude in the Sardinian expedition, 1053 σ-stars were observed, 3 of which were identified as K^--events and one as the capture of a negative hyperon.

This identification was made possible through systematic mass measurements made on the tracks of the σ-mesons.

We have eliminated those events in which the primary meson track was steeply inclined with respect to the emulsion plane making measurements difficult.

The grain density of 750 σ-meson tracks so selected were measured to determine the mass of the particle.

Beginning 2 mm from the σ-star and for 250 μ, a grain count of about 200 grains of the meson track was made.

These grain density values were then corrected taking into consideration the inclination of the track with respect to the emulsion plane, the depth of the track in the emulsion and the value of the « minimum » grain density at the point at which the measurement was made.

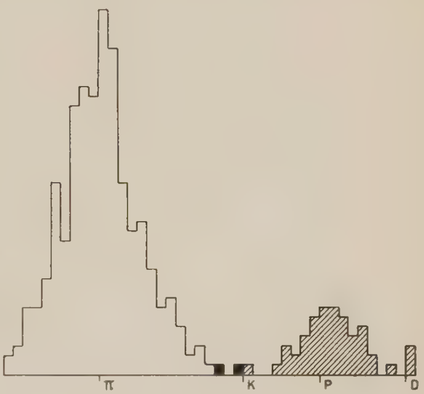


Fig. 1.

□ π-Mesons; ■ K-Mesons; ▨ Protons

Similar measurements were made for protons coming to the end of their range in the emulsion. From these grain density values it has been possible to deduce the mass of the σ-mesons; the distribution for 310 events is shown in Fig. 1.

(*) Called σK by the Committee for the K-mesons (see in this issue, pag. 444).

Those σ-mesons whose resultant mass value was greater than 500 m_e were further examined and more accurate measurements of ionization and scattering measurements were made.

We have in this way identified 3 examples of the nuclear capture of a K^--meson and one example of the capture of a negative hyperon. We will now describe briefly the 3 K^--meson events. The negative hyperon event is discussed in another paper [1].

The first event (Fig. 2) was produced in a disintegration of the type 6+1p. The heavy particle traversed the emulsion stack for a range of 11.1 mm and on coming to rest produced a nuclear disintegration from which a light meson was emitted. This meson in turn came to rest without producing a visible interaction or decay and from direct measurement of its mass has been shown to be a π-meson. In the second event, the K-meson was emitted from a nuclear disintegration 9+1n. After a range of 47 mm the particle came to rest and produced a disintegration in which 2 heavily ionizing particles were emitted, which were identified as protons. In the third event (Fig. 3) the K-meson was emitted from a disintegration, 5+1n, came to rest after a range of 75.1 mm and produced a disintegration in which 3 protons and an α-particle of small energy were emitted.

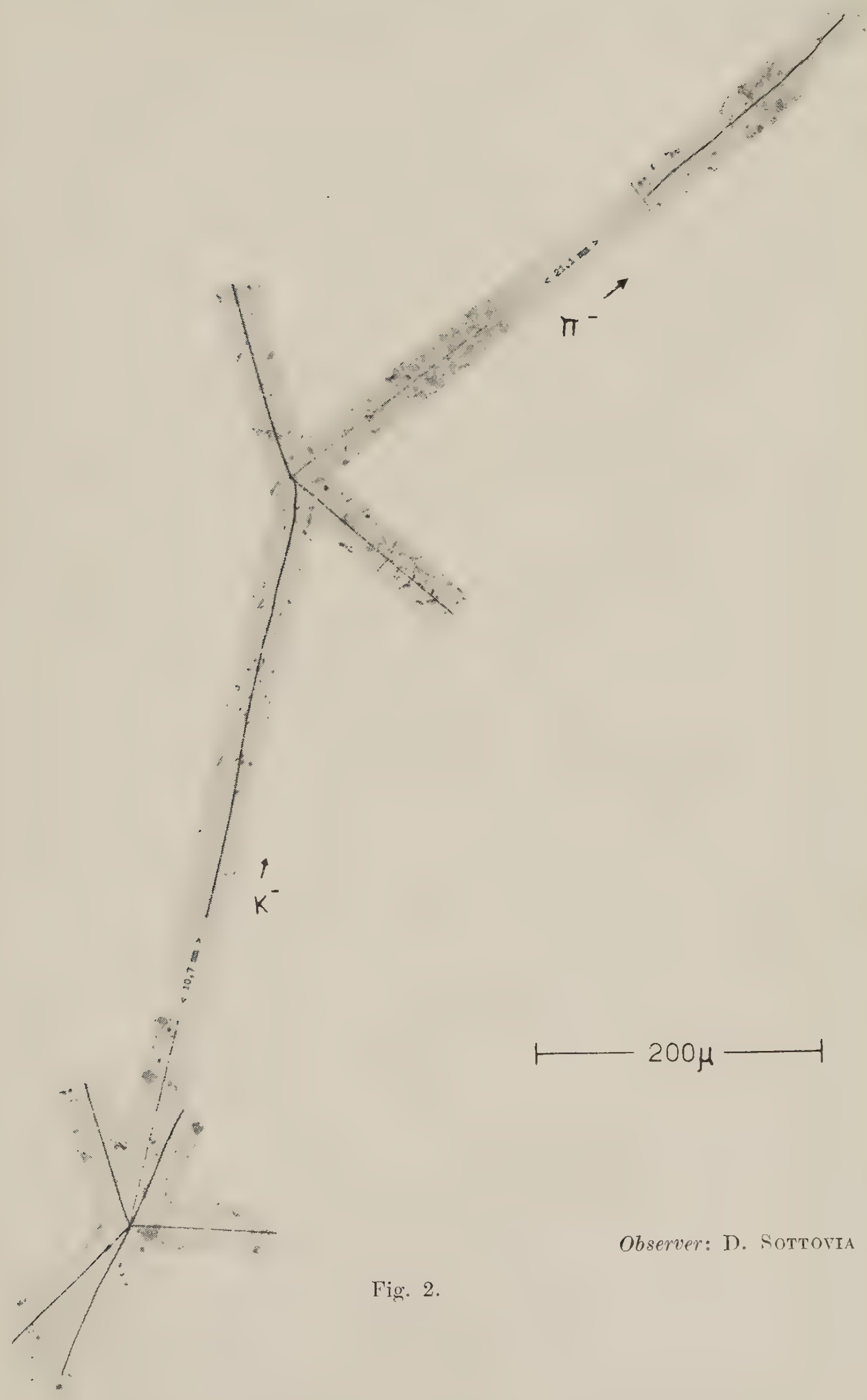
The details concerning these events are presented in Table I.

TABLE I. – *Interacting K-particles.*

Particle	K^--meson			Capture star				
	Mass in m_e	Parent star	Range (mm)	Identity and energy (MeV) of the charged secondary particles				Total visible energy + bind. energy (Mev)
K^--Pd_1	1070±160	6+1p	11.1	p 42	p 17	π^- 37	recoil	252
K^--Pd_2	985±150	9+1n	47.0	p 13	p 11			40
K^--Pd_3	987±120	5+1n	75.1	p 7	α 7	p 90	p 45	178

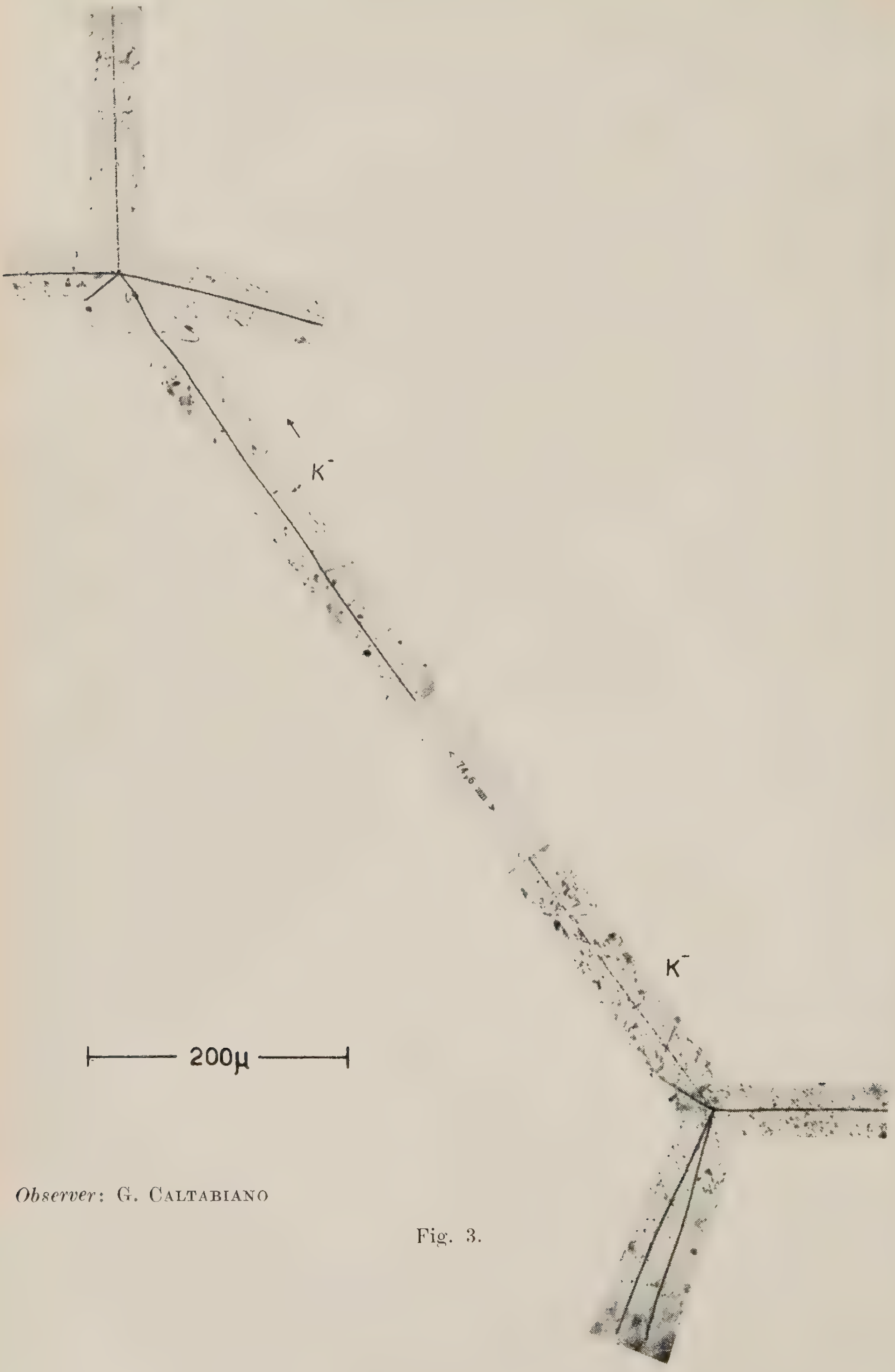
In Table II are presented the frequencies of occurrence of K-mesons and other heavy particles that were observed in Padua in stripped emulsions.

(1) M. BALDO, G. BELLIBONI, M. CECCARELLI and B. VITALE: see in this issue, pag. 289.



Observer: D. SOTTOVIA

Fig. 2.



Observer: G. CALTABIANO

Fig. 3.

These events were observed in normal scanning with a total magnification of 225.

TABLE II. – *Frequency of heavy particles.*

Method of identification \ Identity	Stars	π^+	σ	$\tau + {}^{(\tau)}K_\pi$	K	σK	Y^+	Y^-
Ordinary scanning	20 500	833	1 053	2	8	2	1	
Following back of π-mesons				2				
Revision						1	1	1

The ratios deduced from these results are subject to correction due to loss in scanning which, although they should be quite small for σK- and τ-meson ev ents, should be comparatively larger for K-decay and hyperon-decay events.

Discussion of Stars Produced by Negative K-Mesons.

N. DALLAPORTA and G. LANZA (*)

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

Stars produced by the capture and nuclear absorption of negative K-mesons at the end of their ranges have recently been observed in different laboratories.

It is known that the principal characteristics of these stars are that sometimes a π-meson is emitted, and that in general the total energy shared between all charged secondaries observed is rather low compared with the total energy of about 500 MeV available due to the K^--capture. Furthermore their frequency is much lower than the number of K-mesons decaying at rest in the emulsion.

These peculiar features of these stars give rise to the problem of their origin and of the mechanism of their production. As the simplest approach, we have tried to see if it is possible to interpret the experimental features without introducing any new mechanism of K^--capture, and trying to apply to this process the current ideas already known from other types of interaction.

Some calculations of this kind have already been carried out [1]; we shall try to complete them with a precise analysis of the possible cases. The only K -decay schemes now recognised with certainty are the $\varkappa$- and τ-decay schemes:

$$\varkappa \to \mu + ? + ? , \qquad\qquad \tau \to 3\pi .$$

We shall consider here only the cases deriving from the possible simple interactions of these two particles, and examine the three following possibilities: 1) $\varkappa$-particles are weakly interacting with nuclei; 2) τ-particles are weakly interacting with nuclei; 3) $\varkappa$- or τ-particles are strongly interacting with nuclei.

(*) Now at the Cagliari University.

1. – $\varkappa$-Mesons weakly Interacting with Nuclei.

This case has already been studied by one of us [2]. If one assumes the $\varkappa$ to be fermions interacting according to the scheme

$$\varkappa^- + \mathrm{p} \to \mathrm{n} + \nu,$$

then, from the Fermi interaction constant between them and the nucleons, one may calculate the ratio of $\varkappa$ captured by the nucleus to $\varkappa$ decaying when bound in the K orbit. The result is that the ratio of total number of captures to total number of $\varkappa$ both positive and negative, bound either to light or heavy nuclei turns out to be about 0.1. In this case there is no apparent difference between light and heavy nuclei for the decay of the bound $\varkappa$ because the decay products are all weakly interacting, and they are not expected to give secondary interaction events. Therefore the bound negative $\varkappa$-decay will not be distinguishable from the positive one.

The captures give rise to a neutron of about 130 MeV which originates a disintegration star. We have tried to predict approximately the type of these stars by comparing them with those obtained by 130 MeV protons studied by LEE *et al.* [3] and HODGSON [4]. Some changes however have to be made to their results to take into account the fact that the primaries of their stars were protons.

Very roughly this may be accounted for in the following way: PUPPI *et al.* [5] have made Montecarlo calculations for σ-stars considering the two possibilities that the π-meson is captured by a pp pair or a pn pair of nucleons. The main experimental difference between these cases is in the relative number of 0 prongs stars, which is only 6% in the first case and 17% in the second. We have then corrected the experimental distribution of LEE *et al.* by increasing the number of the 0 prongs stars in this ratio and then normalizing to 100. In this way we obtain the results quoted in Table I, which we expect to represent approximately the size distribution of stars produced by $\varkappa$-capture.

TABLE I.

Number of prongs	0	1	2	3	4	5
Number of stars	16	21.3	35.4	20	6,5	0.8

2. – τ-Mesons Interact Weakly with Nuclei.

In this case we must distinguish between capture of the τ-meson in the K orbit:

a) of a light nucleus

or

b) of a heavy nucleus.

In case *a*) the τ is bound in a K orbit outside the nucleus. If it decays, the probability that all three π are emitted without interacting with the nucleus is quite high. But the nucleus takes some momentum, and we can calculate its probability distribution simply on statistical grounds. It turns out that this probability has a sharp maximum for a momentum of the nucleus of about 30 MeV/c. This τ will then generally not be coplanar and the angles of the π's with the momentum of the nucleus may be of about 70°.

In case *b*) the τ is bound in a K orbit inside the nucleus. When it decays, the π created inside the nucleus will in general have little chance of coming out without interacting with nucleons. It is then expected that the event shall appear as a star with possibly one or more emitted π's.

To predict the characteristics of these stars, we have first considered what may happen to the π-mesons released inside the nucleus. They may be scattered with or without charge exchanges or absorbed. The scattering cross-sections of low energy mesons on nucleons are now well known from the experimental work of FERMI *et al.* [6], but there is at present much uncertainty concerning the absorption cross-section of the meson. Moreover it may be expected [7] that for low energy π's the Coulomb potential inside the nucleus will accelerate the negative and slow down the positive π's so that the behaviour of π's of different sign will be quite different. Finally, we have to consider that the results relative to the scattering of the π's in light nuclei as interpreted with the optical model seem to point out that the π's in the nucleus are subject to an attractive nuclear potential as a whole. Tentatively we have calculated the mean free path of the π's in the nucleus assuming the experimental Fermi scattering cross-sections and the absorption cross-sections given by TENNEY and TINLOT [8]. The π's in the nucleus are considered to move inside a potential hole about 20 MeV deep; coulomb effects on low energy π's inside the nucleus have been disregarded while the barrier effect when they come out is considered. Assuming the production spectrum $\Pi(E)$ of the π's to be the same as the spectrum obtained experimentally for the secondaries of free τ's [9] we have calculated the mean probability of escape of a τ according to the formula

$$\frac{\Sigma \Pi(E) \exp\left[-\dfrac{R}{\lambda(E+V)}\right] T(E+V)}{\Sigma \Pi(E)}$$

where V is the potential barrier, T the trasmission coefficient, λ is the total mean free path and R is the radius of the nucleus. The result is about 0.10.

The results have been compared with a Montecarlo calculation for a π of 40 MeV that emerges from the disintegration of the τ. The results indicate that some of the scattered π's have enough energy left to be able to come out of the nucleus. Therefore, as in the preceding calculation the scattered mesons were considered as if they were absorbed it is necessary to increase somewhat the preceding result. As a mean value we have taken $P = 0.14$.

As a general result the probabilities for the outgoing of 0, 1, 2 or 3 π's emerging from the τ in heavy nuclei are given in Table II.

TABLE II.

No. of π's	0	1	2	3
Emergence probability	0.636	0.310	0.050	0.0027

The energy released when a π is absorbed as well as the recoil nucleons when the π's scatter will give rise to the prongs of the star. These have been calculated using the Montecarlo stars obtained by PUPPI *et al.* [5] for π^- capture; for π^+ capture the results of PUPPI are used interchanging protons and neutrons. When two or three π's are captured we extract two or three π stars and add the results. We add to this some contribution due to the recoil nucleons from the scattering of the π's. The Montecarlo calculation on the behaviour of the π in the nucleus shows that the mean probability of scattering is about 0.4. This generally gives a recoil of the same energy as the evaporation tracks, which is generally a neutron for scattering of π^- and a proton for scattering of π^+.

In this way the probabilities of emission of 0 or 1 recoil proton can be calculated; they are found to be:

number of protons	0	1
corrisponding probability of emission	0.6	0.4

These contributions added to the preceding ones give as the final result for the stars from which 0, 1 or 2 π's emerge, the values of Table III.

In the following we shall indicate with:

A, the number of stars without any ionizing prong.

B, the number of stars with only black prongs ($E < 30$ MeV).

C, the number of stars with at least one gray prong ($E > 30$ MeV).

The bracketed figures in each case indicate the most probable number of ionizing prongs to be expected for the corresponding type of star.

TABLE III.

Type of stars	Without mesons	With 1 meson	With 2 mesons
A	0	2	9
B	23.5 (4)	48 (2)	64 (1)
C	76.5 (6)	50 (4)	27 (3)

3. – Strong Interaction of K.

As the simplest possibility we consider the case in which the K is captured by a pair of nucleons. The 500 MeV energy available in the centre of mass system of the nucleon-pair may then be shared as kinetic energy between the two nucleons, or may give rise to one or more mesons. As no experimental data on the production cross-section of mesons in nucleon-nucleon collision are available it is rather difficult at present to predict with any accuracy what are the probabilities of emission of one or more mesons. As a very rough estimate, we may assume that the proportion of stars without emerging mesons may be found from the experimental results of Bristol [10] on meson production in high energy stars, that are given in the first row of Table VI.

We consider the following schemes of capture:

α) Capture by a pn pair:

$$\mathrm{K^- + p + n \rightarrow n + n}$$
$$\mathrm{K^- + p + n \rightarrow p + n + \pi^-}$$

β) Capture by a pp pair:

$$\mathrm{K^- + p + p \rightarrow p + n}$$
$$\mathrm{K^- + p + p \rightarrow p + p + \pi^-}$$

γ) Capture by a nn pair; the only possible case is:

$$\mathrm{K^- + n + n \rightarrow n + n + \pi^-}$$

According as 0 or 1 meson are produced, the two nucleons have about 500 or 300 MeV energy available, which gives rise to a star. To predict the characteristic of these stars, we have made a Montecarlo calculation for the

500 MeV case in heavy nuclei, following the exact procedure outlined by PUPPI *et al.* [5] in their work on π capture stars.

The case of stars generated by the pp pair for an energy of 150 MeV, which is not given by PUPPI, has been tentatively obtained by changing the numbers of different types of stars from the pn case in the same ratio as done when changing from the nn case to the pn case, and normalizing to 100. The case of stars of about 300 MeV has been obtained as an interpolation between the 500 MeV and 150 MeV cases.

This data are summarized in Table IV.

TABLE. IV. – *Characteristics of stars generated by a pair of nucleons of different energies in the center of mass system* (C.M.S.).

Pair	Energy in C.M.S. of the two neutrons	500 MeV	300 MeV	150 MeV
nn	*A*	15.9	20	24
	B	29.2 (1)	45 (1)	62.5 (1)
	C	54.9 (2)	35 (2)	13.5 (1)
pn	*A*	—	2.6	5.6
	B	10 (2)	31 (2)	52.8 (2)
	C	90 (3)	66.4 (3)	41.6 (2)
pp	*A*	—	0.7	1.4
	B	—	18.5 (3)	37 (2)
	C	100 (4)	80.8 (3)	61.6 (3)

We then obtain, for the three capture schemes before considered, the types of stars listed in the following Table V.

TABLE V.

Type of star	Scheme α) capture by pn pair		Scheme β) capture by pp pair		Scheme γ) capture by nn pair
	0 mesons	1 meson	0 mesons	1 meson	1 meson
A	15.9	2.6	0	0.7	20
B	29.2 (1)	32 (2)	10 (2)	18.5 (3)	45 (1)
C	54.9 (2)	66.4 (3)	90 (3)	80.8 (3)	35 (2)

In this way no account is taken of π^0 mesons production and of reabsorption of mesons. Although the use of any theory of meson production may appear questionable, we can try to use the Fermi theory cross-sections to improve the provisional preceding results. As a first step, we may assume the results of FERMI [11] for the production of different numbers of mesons of different signs for an energy of 500 MeV in the center of mass system (for nn nucleon pair, we may take the results of FERMI for a pp pair just by changing p in n and π^+ in π^-). We calculate then the probability of emergence for a meson in a similar way as already done in case *b*). Although the cross-sections are different we have used the same results also for π^0, as we are interested only in the order of magnitude. For the production spectrum we have tried the $1/E$ and $1/E^2$ law; the results are 0.10 for the first case and 0.12 for the second; they are therefore very insensitive to the exact shape of the spectrum. For the same reason as in case *b*) ,we increase this value to about 0.15.

The final results are given in the last three rows of Table VI which is obtained by combining together both probabilities of creation and reabsorption. It is seen that the probabilities of creation of π-mesons although very high in

TABLE VI.

Number of emerging mesons	0	1	2	3	
Number of stars according to Bristol data . .	70		30		
Number of stars according to Fermi theory .	84.1	15.1	0.8	$\sim$0.01	scheme α)
» »	86	13,3	0.69	0.01	scheme β)
» »	83.4	16.2	0.7	$\sim$0.02	scheme γ)

the Fermi theory are very much reduced by the absorption, and become lower than the Bristol values. If we remember that these calculations are made for heavy nuclei and that of course for light nuclei the reabsorption of mesons is much lower, we see that the Bristol results may be not inconsistent with the Fermi cross-sections. We must now calculate the type of star associated with the preceding different cases. Therefore, for each of the Fermi cases we consider how much mean energy is left to the two nucleons which result from the absorption of the K-meson, and associate with it the corresponding mean star as taken from the Table V. However we have disregarded the case in which three π's are produced, in consequence of its low probability. We have also disregarded the corrections as done in *b*), due to the scattering of

the mesons. This means that the values obtained for stars with no ionizing prongs are to be considered as upper limits. Adding all the cases that appear as the same type of star, we obtain as final results for the stars associated with the emission of 0, 1 or 2 π's the values given in Table VII.

TABLE VII.

	Type \ Star with	0 mesons	1 meson	2 mesons
Stars produced by K$^-$ capture from pn pair (Scheme α))	*A*	1.44	3.7	10.5
	B	28.5 (3)	40.2 (1)	54.8 (1)
	C	70.1 (4)	56.1 (2)	33.7 (2)
Stars produced by K$^-$ capture from pp pair (Scheme β))	*A*	0.1	3.2	8.2
	B	19 (2)	33.6 (2)	51.7 (1)
	C	80.9 (3)	63.2 (2)	40.1 (1)
Stars produced by K$^-$ capture from nn pair (Scheme γ))	*A*	3.3	12.2	23.9
	B	48.8 (4)	50.7 (3)	62.7 (2)
	C	47.9 (4)	37.1 (3)	13.4 (2)

4. – Discussion of Results.

Of course, it is by no means actually possible to make a real comparison between these results and experimental data. Not only are the statistics far too low, but it is higly probable that the sample of K-stars we have collected is by no means representative of the true proportion of different types of stars. The experimental selection is biased because K-stars from which a π emerges are much more easily detectable than the others. Therefore we think that the high percentage of experimentally found K-stars with a secondary π cannot be considered as an indication of the true proportion, which may be consistent with the values calculated in one of our models.

Nevertheless our considerations may actually be used in a qualitative way, especially in what concerns the proportion of energy which we expect to be shared between the ionizing particles.

It seems to us then that what can be said already with a rather high probability is that either negative τ's exist in a very low proportion, or if they are abundant, they cannot be weakly interacting. In fact, we know from

cloud chamber evidence that the negative τ's exist; but it is at present rather difficult to say anything about their relative frequency to positive τ's. If τ's were weakly interacting and both positive and negative were present in about the same number and if we admit that as for π-mesons the probability of capture in a light atom orbit is about 50%, we ought to have already observed many no coplanar τ-decays. On the other hand, the stars occurring as a consequence of negative τ-decays bound in a heavy atom would give rise to stars that generally speaking are expected to be larger (most probable values 5 to 7 ionizing prongs when a π is emitted) than the sample of experimental stars now available.

It is of course actually impossible to decide if other heavy mesons besides the τ are captured, and all we can say is that if the proportion of negative K's is not very low compared with that of positive ones, as some measurements of the Paris cloud chamber group could indicate [12], it does not seem that all other types of K interact, because otherwise we should expect a much higher proportion of K-stars. If all other K's were fermions and no other heavy mesons should interact strongly except the τ, we should nevertheless still expect, according to our hypothesis 1), some other K-stars to be formed which would increase the percentage of π-less stars and would make the proportion of K^- captures slightly higher than the τ proportion. An answer to this question may be obtained only when rather exact values of the frequencies of occurrence of both τ and K^- are available.

If we accept that at last the τ's are strongly interacting, we can try to see whether the stars calculated with the models of case 3) seem to fit the present indications from experimental data. In this respect it may be said that the three hypothesis of capture from a pn, pp or nn pairs give somewhat different results either according to the rough calculation of Table V, or, in a slightly less sensitive way, according to the more refined ones of Table VII. In the rough calculation case, while the capture by pn would give the right order of low energy stars without π the same could be said for the capture by nn for the stars with a π; the capture by pp would give results quite inconsistent with the experimental ones. For the more refined calculations, we find that the best fit with present data would be obtained for capture by nn. In particúlar only in this hypothesis the interesting Rome event [13] (a single negative without any ionizing prong from the star) could have a not too low probability to allow to interpret it in this way. Also in this case, the pp capture hypothesis seems rather inconsistent with present data.

These data are however so sparse up until now, that it could not be possible actually to say much more than this; the present calculation may be useful as soon as more experimental data will be available. Of course, if experimental data on meson production cross-sections in nucleon collisions that will probably soon be available through cosmotron experiments prove

somewhat different from the theoretical ones used here, the calculations will have to be consequently modified.

* * *

It is a pleasure to thank Prof. G. PUPPI for many interesting discussions on the subject and for having put at our disposal the original data of the Montecarlo calculations on σ-stars made by himself and his coworkers of the Istituto di Fisica di Bologna, and Mr. G. COSTA for his very valuable help in making the Montecarlo calculations.

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Two Examples of Nuclear Interaction of K-Particles at Rest.

M. DI CORATO and B. LOCATELLI

Istituto di Scienze Fisiche dell'Università - Milano
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

G. MIGNONE and G. TOMASINI

Istituto di Fisica dell'Università - Genova

In a normal scanning of stripped emulsions of the Sardinian flights (1953), two events have been found of the type σK. One of these, $GeMi_1$, was easy to distinguish from a normal σ-star since one of the secondaries decayed in flight before leaving the emulsion; the primary of the other, $GeMi_2$, was recognized by eye, during the revision of all stars, as moving towards the centre of the star and as being heavier than a σ-meson.

Measurement of mass of the primaries of the events, using the constant sagitta method as calibrated by DI CORATO *et al.* (*), gave the values:

$$\text{Mass of primary of } GeMi_1 \ldots \quad 1170 \pm 230 \ m_e .$$
$$\text{Mass of primary of } GeMi_2 \ldots \quad 970 \pm 90 \ m_e .$$

These values were not corrected for distortion.

In Table I are given the detailed results on these two events. About $GeMi_2$ there is little more to say. It enters into the main cathegory of K-particles found to date, in which very little of the rest mass of the K-particle appears as visible energy in the star.

$GeMi_1$, however, is stated to contain a possible Y_L-particle (**). We will now proceed to justify this statement.

The event is shown in the photograph (Fig. 1). Track *B*, which gives rise, without stopping, to track *C*, was interpreted as due to an unstable particle of short life. Measurements of scattering and of ionization (blob counting) on tracks *B* and *C* gave the results shown in Table II. No measurements other than range

(*) M. DI CORATO, D. HIRSCHBERG and B. LOCATELLI: see in this issue, pag. 381.
(**) See the *Report of the Commitee on Charged Hyperons*, in this issue pag. 448.

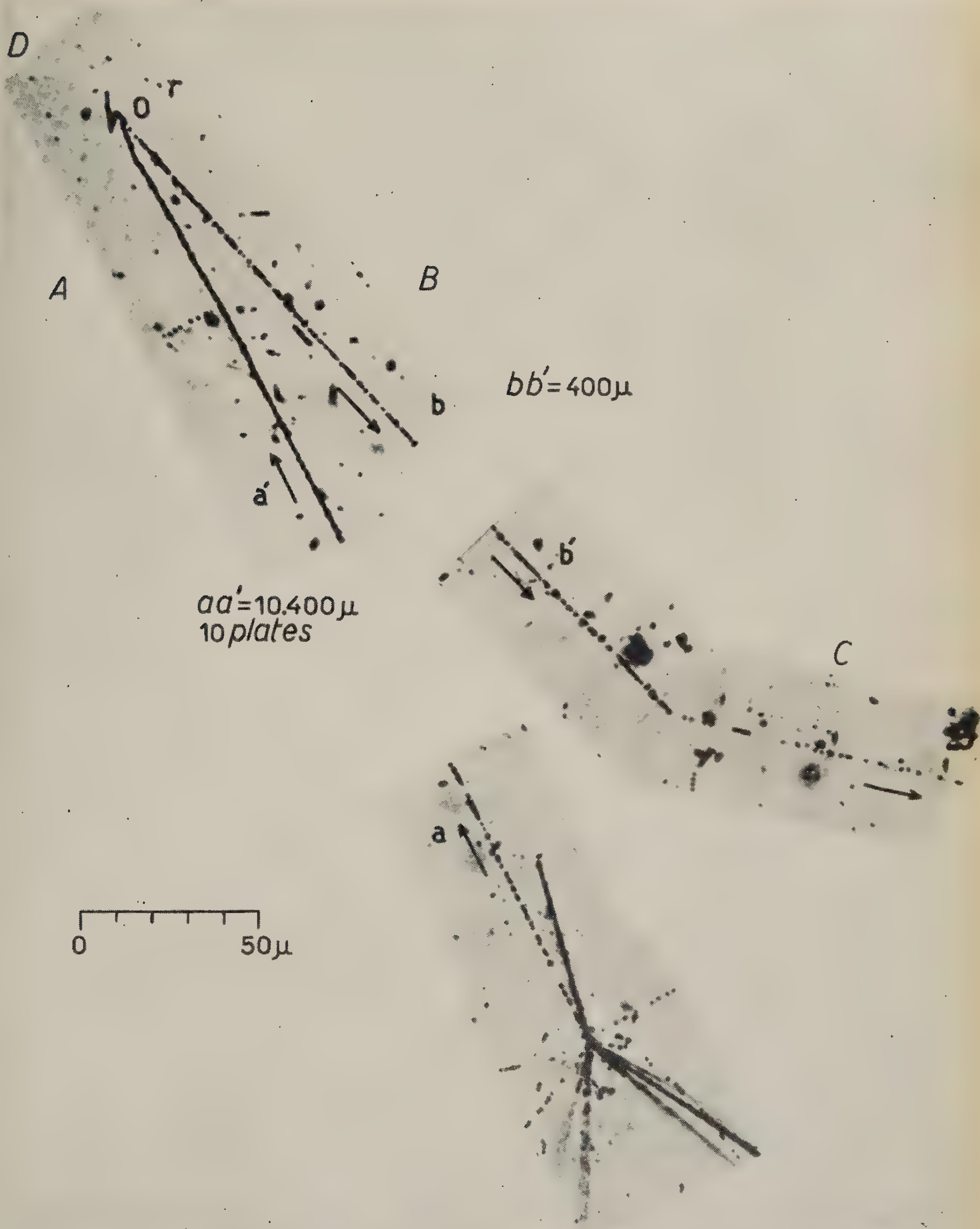

Fig. 1.

TABLE I.

Particle	Parent star	Primary		Secondaries			
		Length (mm)	Mass (const. sag.) (m_e)	Range (μ)	Identity	Energy (MeV)	Visible energy release
σK-GeMi$_1$	10+2n	10.64 (10 plates)	1170±230	16 600	p, d; π Y_L	~ 1 ~ 60	~ 60
σK-GeMi$_2$	7+4p	41 (16 plates)	970± 90	284 1 508	p p e slow	6.7 18.3	25

are possible on track D (16 μ long). It appears to be a singly charged particle.

In the calculation of $p\beta$ account has been taken of the 8% uncertainty on the scattering constant. The velocity along the track B has been deduced from a calibration curve drawn through points obtained in 6 protons contained entirely in the same plate as the event.

TABLE II.

Track	Length (μ)	$\bar{\alpha}_{100}$ not corrected for distortion	$\bar{\alpha}_{100}$ corrected for distortion	$p\beta$ not corrected for distortion (MeV/c)	$p\beta$ corrected for distortion (MeV/c)	g blobs / 100μ	β_p velocity of proton of equal g	g^*	Mass (m_e)
B	600 μ	0.192	0.171	125±50	140±60	39±3	0.31 ±0.2	5.6 ±0.4	2 700± ±1350
C	26400 μ	0.13	—	204±21	—	22±0.2	0.86	1.07±0.02	probab. π

The secondary particle C is certainly lighter than a K-particle. If we assume it to be a π-meson, and calculate the Q-value of the decay scheme

$$Y_L \to \pi + n + Q ,$$

we obtain the value

$$Q = 95 \pm 21 \text{ MeV} ,$$

which is consistent with the mean Q value of the Y_L-particles (see in this issue, pag. 456); the particle B is therefore interpreted as such. The mass of the particle B on this assumption is about 2300 m_e and its kinetic energy of emission 60 MeV.

The interest of this event lies in the fact that it shows that in the interaction of a K-particle with a nucleus, one of the nucleons can be excited and ejected in the form of a hyperon. The mechanism of this interaction is not immediately evident; we do not know for instance how many nucleons are involved in the process. The energy given to the nucleus is ~ 500 MeV (rest mass of the K-particle). The energy apparent in the interaction is:

$$(\mathrm{Mass}_{\mathrm{Y_L}} - \mathrm{Mass}_{\mathrm{N}}) + (\text{Kinetic energy})_{\mathrm{Y_L}} + (\text{Binding energy})_{\mathrm{N}} + \\ + \text{Energy of particle } D$$

which gives ~ 310 MeV if D is a proton or deuteron and ~ 450 MeV if D is a π-mesons.

An event which can be interpreted in a similar way has been described by BUTLER at the Rochester Conference. A negative particle observed to stop in the lead plate in a Wilson cloud chamber is associated with a V_1^0 particle, which seems to come from the end point of the negative particle.

Photo-Electric Identification of Negative K-Mesons.

S. VON FRIESEN

Department of Physics of the University - Lund

A large number of particles coming to rest in nuclear emulsions have been measured in Lund by means of the photo-electric method in order to study the distribution of the mass values. It was found that the individual groups, e.g. the π-meson and the proton groups, show a standard deviation of 10% or less when the tracks are chosen at random from all regions of the plate. With neighbouring tracks only the deviation is considerably smaller. In the course of the investigation three K-particles have been found which show neither decay nor visible interaction at the end of their range (*). Their average mass is 920 m_e. The data are given at the bottom of Table I. The mass of K-Lu_3 from range-scattering measurements is 1100 ± 185 m_e. The other two particles are too short to be measured in this way. Two of the tracks

TABLE I. - *Photo-electric* K-*meson Masses.*

Particle	Mass (m_e)	Range (μ)	Sign	Secondary
K-Br_1	1490 ± 100	4100	+	$g^* \sim 1$
K-Br_6	1470 ± 100	2500	+	$g^* \sim 1$
K-Br_2	1170 ± 150	2800	+	μ
K-Br_5	1110 ± 130	1400	+	μ?
K-Ko_3	1110 ± 160	2500 (1000)	+	$g^* \sim 1$
K^--Lu_4	985 ± 70	1800	—	star, 3 prongs
K-Lu_2	960 ± 70	3300	(—)	0
K-Lu_1	905 ± 70	3450	(—)	0
K-Lu_3	890 ± 90	5700	(—)	0

(*) *Arkiv för Fysik* (in print).

were found in an emulsion flown at Lund at a top altitude of 34 000 m. The g_{min} of this plate was 25 grains per 100 μ. The third track was found by ALINDER in a plate flown in Sardinia in 1952 at 27 000 m. It was less strongly developed, but the decay electron of a μ-meson could be recognized quite easily very close to the K-meson.

Another K-meson has been found in the plate Pd 144 flown at 26 000 m in Sardinia last year. It emerges from a star of three prongs, one a 200 MeV proton, the other a thin track and comes to rest after 1 820 μ giving rise to another 3-prong star. One of the prongs is an identified proton of 22 MeV, the second is very short and the third is a thin track which leaves the emulsion after 1 600 μ and is so much scattered that it is likely to be a π- (or μ-) meson. The mass of the K-meson has been determined photo-electrically to be 985 ± 70 m_e. The event can be explained as a negative τ-meson giving a star (see Fig. 1).

If we follow a suggestion made by POWELL at Bagnères-de-Bigorre and assume that negative τ-mesons give stars but negative $\varkappa$-mesons don't, then the three particles which show neither decay nor visible interaction can be explained as negative $\varkappa$-mesons.

The upper half of Table I shows the mass values of the other K-mesons which have been measured at Lund so far. It can be seen that the nine particles fall into different groups, with the approximate masses 1500, 1100, 970 and 920 m_e.

The measurements are being continued on 8 other K-mesons which have been found in the Sardinian plates. Some of these tracks are exceptionally well suited for precise measurements, because of their length and the excellent quality of the emulsions, processed at Padua.

Fig. 1.

Fig. 1.

Two K⁻-Interactions.

I. MACPHERSON, J. V. MAJOR, OM PARKASH, G. D. ROCHESTER
and A. M. SHORT

The Physical Laboratories of the University - Manchester

1. – Introduction.

Two τ-mesons and 3 K-particles have been found in 11 cm³ of G5 emulsion exposed at an altitude of 30 000 feet under an iron absorber of 14.5 cm thickness. Of the three K-particles, one decays into a light meson of $p\beta = 124$ MeV/c whereas the other two are absorbed by nuclei of the emulsion to form K-stars. These two mesons are identified as negatively charged K-mesons (*). They were found amongst the events listed in the following Table I.

TABLE 1.

Particles	$\pi \to \mu$	σ	$\mu \to e$	ρ	2 prongs stars	4 prongs stars	p
No. of events	389	509	623	569	1 013	781	15 000

Scanned volume 11 cm³.

2. – Mass Measurements.

The masses of the primary particles were determined by three methods, namely the scattering range, gap-length range and by a photometric method. In the first method, the mean angle of scattering was found by taking sagittal measurements at the ends of constant length cells in the Menon-Rochat method and at the ends of cells whose lengths varied along the track to maintain constant signal to noise ratio as suggested by DILWORTH, GOLDSACK and HIRSCHBERG [1] and BISWAS, GEORGE, LAL, YASH PAL and PETERS [3], employing the $4\bar{D}^2$ cut-off procedure.

In the gap-length method all gaps greater than a certain minimum length

(*) Called σK in the *Report of the Committee on K-Mesons*, in this issue, pag. 444.

Primary					
Particle	Track Length (μ)	Mean Mass by (α, R) and phot. methods (m_e)	Mass (G, R) (m_e)	Particle	Tra Leng (μ
K^--Mn_1	1 620	1 900 $\pm$ 500	1 000 $\pm$ 150	a	29 35
				b	6 4
K^--Mn_2	1 560	1 260 $\pm$ 400 (α, R)	$\sim$ proton	a	
				b	
				c	3

were measured and the integral gap plotted as a function of range. The mass was determined by comparison with protons or π-mesons.

In the photometric method, the number of grains per unit length is effectively measured. The differential grain count is plotted against range. By comparison of the curves of protons, π-mesons and K-mesons, the K-meson masses could be determined.

The masses of the fast secondary particles were found by the scattering-grain density method (DANIEL *et al.*, [3]), the grain densities being determined by counting the blobs of developed grains along the tracks and referring the results to those on fast electrons in the same vicinity ionising in the plateau region.

The measurements and results are given in Table II. The errors are standard deviations. The secondaries of particle Mn_1 have been followed into a facing plate and the two values given for the lengths of the track refer to the two emulsions. The separate $p\beta$, g^* values agree closely; only the values for the whole track are given. The kinetic energy refers to the identification recorded in the last column.

3. – Description of the Events.

Part of the track of particle Mn_2 and the star which it produced are shown in Plate I.

The increase in density of the track towards the star is very striking when the original track is examined and leaves no doubt whatever about the direction of the particle. The particle entered the emulsion through the glass back and interacted after traversing 1600 μ. It made an angle of 30° with

Secondaries					
$p\beta$ (MeV/c)	g^*	Mass (g, α) (m_e)	Kinetic Energy (MeV)	Identification
± 15	1.15 ± .05	200^{+50}_{-40}	54	probably π
—	black	—	> 15	probably p
—	black	—	> 1	probably p
—	black	—	> 1	probably p
—	black	—	> 7.5	probably p

the upward vertical and the interaction took place 1.5 cm below the iron and about 2 mm away from the other K-particle (Mn_3), which after travelling in approximately the same direction for a distance of 3 280 μ decayed into a light meson. The particle Mn_2 was found in the same plate as Mn_1 and Mn_3 but not in close proximity to them; nor did it have the same direction.

Three particles emerge from the interaction induced by Mn_1, a fast particle which has been identified as a π or μ-meson with $p\beta = 96$ MeV/c, a slow, heavily-ionising particle which was probably an « evaporation » proton, and a slow electron, indicated by the unresolved blob of ionisation at the star centre, and which probably resulted from the β-decay of the excited nucleus left after the process of evaporation.

The particle Mn_2 also came to rest at the point indicated by the star, and produced three secondary particles of short range, typical of the evaporation of an excited nucleus.

4. – Discussion.

The events described in § **3** clearly indicate the capture by nuclei in the emulsion of negative particles. The question arises as to their nature and type. Particle Mn_1 could not possibly be a π-meson because the total observed energy released in the star corresponds to a minimum mass of the order of 400 m_e; the mass measurements confirm this fact. The length of track available for measurement is unfortunately too short to obtain an accurate value for the mass, and the different methods yield somewhat different results. It is

thus probable that the mass will be in the range (900-2 400 m_e). From other evidence obtained in this laboratory it appears that the scattering method may not reach high accuracy except for lengths much longer than have been possible here. We would therefore give rather more weight at present to the gap-length method and assume that Mn_1 was a K-meson of mass about 1000 m_e. However we cannot exclude the possibility that Mn_1 is a charged hyperon.

For particle Mn_2 there are only the mass measurements. We assume that this particle was also a K-meson.

The most interesting event is undoubtedly the one induced by Mn_1, and it is of interest to compare the star with those observed by LAL, PAL and PETERS [4]. These authors have described four K^- interactions in two of which one light meson was formed together with small evaporation stars. One of the mesons was identified as a π^--meson with a kinetic energy of (25.3 ± 1.0) MeV. The other meson was probably a π-meson and its kinetic energy was (24.7 ± 0.8) MeV (*). It is probable therefore that the Mn_1-event represents the absorption of a K^--meson and the production of a π-meson. If this is true the kinetic energy of the created π-meson is 54 MeV.

In a recent note AMALDI *et al.* [5] have described an event which is claimed as a $K^- \to \pi^-$-decay. A negative heavy meson of mass 1060 m_e comes to rest and from the end of the track there emerges a light meson of mass about 300 m_e which eventually produced a typical σ-star. The kinetic energy of the σ-meson, which is undoubtedly a π^--meson, is 44.5 MeV. This event is closely similar to the Mn_1-event. We would therefore suggest that the event found by AMALDI *et al.* is probably a K^--star in which a neutron (or neutrons) and a fast π-meson are produced.

* * *

We wish to thank Dr. S. J. GOLDSACK for the benefit of numerous discussions and help with the scattering measurements. The plates were kindly exposed for us in a Comet Airliner by Dr. MENON of Bristol University.

(*) Other examples of this type have been described at this conference by the Copenhagen Padova, Genova and Milano, Lund groups (see in this issue, pag. 223, 257, 270, 273).

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Étoile produite par la capture d'un méson K^- (*).

M. MORAND et TSAI-CHÜ

Laboratoire de Physique de l'École Normale Supérieure - Paris

Dans un paquet de plaques exposées en Sardaigne, nous avons observé un méson lourd, ayant traversé 9 plaques; son origine n'a pu être observée. Sa trace se termine dans l'émulsion, après un parcours de 16150 μ, en donnnat naissance à une étoile de capture. Le comptage des grains, par comparaison avec des traces de protons, donne une masse de $(1745 \pm 100)\ m_e$. D'autres déterminations de masse (scattering, gaps) sont en cours.

Au point où la trace de ce méson se termine, trois traces prennent naissance:

1) Un électron, dont la trace peut être suivie sur 150 μ environ et dont l'énergie est de l'ordre de 2 MeV.

2) Une trace au minimum d'ionisation (granulation comprise entre 1 et 1,5 fois le minimum d'ionisation) que l'on peut suivre sur 150 μ; en ce point, elle sort de l'émulsion et, jusqu'à maintenant, n'a pu être retrouvée dans l'émulsion suivante.

3) Un méson π^+ que l'on peut suivre à travers 6 plaques et qui se désintègre au repos en donnant un méson μ de 600 μ. Le parcours du π^+ est de 12750 μ; son énergie est d'environ 27 MeV.

Par suite de la valeur très faible de la granulation au minimum d'ionisation, dans ces plaques, l'électron de désintégration du méson μ n'a pu être observé.

(*) Indiqué avec σK dans le *Report of the Committee on* K-*mesons*, dans ce fascicule, pag. 441.

A Speculation on the Capture Mechanism for K-Mesons.

B. TOUSCHEK

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

Six or seven events (according to whether the Rome event is included or not) which can be interpreted as the capture of a K^--meson (*) were known in Rome at the beginning of this conference. It is probably premature to try to extract information from so small a number of events, but it is perhaps not idle to point out some of the features observed so far and to speculate on their possible interpretation.

At the beginning of this investigation we have to make the not very plausible assumption, that all the events observed are due to the same type of K-meson. The only experimental fact to be quoted in favour of this assumption is that the masses of all the events observed may be equal. The fact which seems to indicate the contrary is the surprising variety of decay modes of the K^+-particle, a variety which can hardly be understood assuming a single K^+-particle. This argument may however be mitigated somewhat, by assuming that some of the K-particles have half-integral isotopic spin and thus do not possess a negative counterpart. We shall further assume that the particles which are observed in capture events are Bose particles with isotopic spin 1.

The events to be discussed are listed in Table I. A remarkable feature appears to be the narrow energy-band of π-mesons and the fact that 2 or 3 events (K^--Bo_1, K^--Bo_2, and K^--Ro_1) are probably due to light nuclei. For the first two this seems to be indicated by the low energies of the emerging protons; for the third by the unopposed escape of 320 MeV of invisible energy.

FABRI and I have compared the following possible mechanism for K^--capture with the data listed in the table:

$$K^- + N \to N' + \pi \qquad N = \text{nucleon} \tag{1}$$

$$K^- + N + N' \to N'' + N''' \tag{2}$$

$$K^- + N \to N' + \gamma \tag{3}$$

$$K^- + N \to N' + \pi + \gamma\,. \tag{4}$$

(*) Called σK in the *Report of the Committee on K-Mesons*, in this issue, pag. 444.

(2) and (3) are the processes discussed by FRIEDLANDER and DALLAPORTA, representing analogues to π and μ capture respectively. (1) is the process which one would like to make responsible for τ-production, and (4) has been considered, because it appeared to us that it was necessary to « cool » the event by the introduction of a neutral particle.

TABLE I.

Particle	Primary Mass (m_e)	Decay Products	Energy (MeV)	Visible Energy (MeV)
K^--Bo_1	$1\,000^{+720}_{-400}$	p	1.0	185
		p	0.5	
		π	28.1	
K^--Bo_2	?	p	2.2	199
		p	0.5	
		p	4.2	
		π	29.2	
K^--Bo_3	$1\,015 \pm 210$	p	7.8	> 246
		p	2.1	
		p	4.1	
		p	> 17	
		p	> 180	
K^--Bo_4	850 ± 95	p	8.1	31
		p	9.0	
K^--Pd_1	$1\,000 \pm 160$	p	42	252
		p	17	
		π	37	
K^--Mn_1	$1\,000 \pm 150$	p	> 15	> 210
		π	54	
K^--Ro_1	$1\,060 \pm 50$	π	39	178

If all the events listed are taken at their face-value, (1) can immediately be ruled out because it would give a π-meson of ~ 300 MeV energy.

The processes (2) and (3) have in common that the production of the π-meson is a secondary event. This is not a very probable process in light nuclei. The objection against (3) is that the light particle would carry away too much energy, so that the production of a meson in the secondary process becomes highly improbable.

The expedient of the « coolant » in process (4) is not sufficient to explain easily the low energy releases. On the basis of the Fermi model one would expect a meson-spectrum which is rather flat and extends from 0 to 250 MeV. The spectrum of nuclear excitation would extend from 0 to 110 MeV with a maximum between 30 and 40 MeV.

It appears to us that none of the theories investigated give an easy fit, and that the order of merit of the theories listed above is (2), (3), (4), (1). None of the theories is in direct contradiction with the facts so far observed.

In the theories listed above only stable particles or π-mesons are discussed as secondaries, and we would like to point out that this is not necessarily a simplification, considering the great variety of new unstable particles which can be freely transformed into one another. We have therefore considered the following rather arbitrary possibility for the primary process involved in capture

$$\mathrm{K} + \mathrm{N} \rightarrow \mathrm{Y} + \pi\,, \tag{5}$$

in which Y is a hyperon. Together with this process we must also assume the possibility of the process

$$\mathrm{K} + \mathrm{N} + \mathrm{N}' \rightarrow \mathrm{Y} + \mathrm{N}''\,, \tag{5'}$$

since the meson interacts strongly with nuclear matter. We want to choose the mass of the Y to be such that the π-meson emitted in the process would have an energy inside the band $28 < E_\pi < 54$ MeV. We find that if it is assumed that E in process (5) with a neutron at rest would be 40 MeV the energy band can be explained in terms of the internal motion of the nucleons (which gives a band width of about 30 MeV). In this way we find

$$M_{\mathrm{Y}} = 1\,240\ \mathrm{MeV} \tag{6}$$

for the mass of the hypothetical hyperon. All the events listed in the table can be easily explained if it is assumed that the Y interacts strongly with nuclear matter. The event K^--Bo_1 and K^--Bo_2 (and probably the K-Ro_1) would correspond to the case in which a neutral Y escapes (a probable process in a light nucleus). The K^--Bo_4, K^--Pd_1, K^--Mn_1, K^--Lu_4 events are attributed to nuclear interaction of the Y in a heavy nucleus, and K^--Bo_3 could be attributed to process (5′) with reabsorption of the Y.

At the beginning of this conference we have been informed by Dr. TOMASINI that a K-star has been observed, in which a hyperon with energy ~ 70 MeV is seen to emerge from a star together with one as yet undefined particle of very low energy. Assuming for the hyperon π-n decay its Q-value has been determined as 93 ± 40 MeV. The value which one would expect from (6)

is 160 MeV. This is just outside the errors given. The kinetic energy of the particle could be understood on the basis of process (5′) which leads to the partition of an energy ~ 200 MeV between a hyperon and a nucleon, which in the case in question would have to be a neutron.

Further K-events have been reported from Bombay, Manchester, Milan, Copenhagen and Lund. The latter two are of particular interest, since they contain one fast particle each, in the Lund event a π-meson. Such a fast meson could be explained by a theory of type (1), but not by (2), (3), (4) and (5).

From this we might conclude that the capture of K-particles can not be attributed to a single mechanism. If this is the case much better statistics will be needed before one can venture on a theoretical analysis.

A Possible Example of the Decay in Flight of a θ^0.

M. Di Corato, C. C. Dilworth and L. Scarsi

Istituto di Scienze Fisiche dell'Università - Milano
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

A two branch star has been found during the systematic scanning of a stack of stripped emulsions exposed in the Sardinia flights (1953).

One of the branches of the star is identified as being that of a π -meson by the presence of a sigma star at its end. The total range of the π^- is $1825 \pm 70\ \mu$. (Energy 8.76 ± 0.20 MeV).

The other branch has grain density very close to that of the minimum for the plate.

There is no recoil nor electron track at the apex of the star, the angle between the two tracks is $23^\circ 57' \pm 10'$ and the fast particle is inclined at 45° to the vertical moving downwards.

In the idea that this event could represent the decay in flight of a neutral particle, scattering measurements were made on the minimum track, following it through three plates to the point at which the third plate had been cut. The total length so measured was 16 mm.

The angle of scattering being small and the distortion in the plates rather high, careful correction was made for the distortion on each section of the track.

In Table I are given the values of $\bar{\alpha}_{100}$, the angle of scattering, and of $p\beta$ for each separate section of the track, obtained:

a) from the measurements of scattering without correction for distortion;

b) with the correction for distortion obtained by subtracting from the mean value of D_{exp} the second difference of the sagitta of scattering, the sagitta of distorsion [1]

$$\overline{D^2_{\text{scatt}}} = \overline{D^2_{\text{exp}}} - \frac{n^4-1}{n^3-1}\left[\frac{2\delta_{\max}}{(N/2)^2}\right]^2 ,$$

where

n = ratio between the cell length of scattering and that of noise;

$\delta_{\max}$ = value of the sagitta of distortion measured both on the track itself and on steeply dipping tracks in the same field ($\times 100 \times 13$) along the whole length of the track measured;

N = number of cells of measurement (cells of noise).

This correction has been applied solely on those portions of the track for which the distortion gave a constant regular deformation. The other sections have been eliminated from the results.

The error given in this case is a combination of the usual statistical error plus that due to the uncertainty on $\delta_{\max}$. In deducing the $p\beta$ from the angle of scattering, account has also been taken of the uncertainty of 8% in the value of the scattering constant [2]:

TABLE I.

Plate	Length (μ)	(a)		(b)	
		$\bar{\alpha}_{100}$	$p\beta$ (MeV/c)	$\bar{\alpha}_{100}$	$p\beta$ (MeV/c)
1	2 500	$(4.3 \pm 1.2) \cdot 10^{-2}$	590^{+240}_{-140}	$(2.2 \pm 0.65) \cdot 10^{-2}$	$1\,150^{+500}_{-260}$
2	6 500	$(4.36 \pm 0.74) \cdot 10^{-2}$	580^{+140}_{-90}	$(3.23 \pm 0.8) \cdot 10^{-2}$	790^{+270}_{-170}
3	6 000	$(3.5 \pm 0.6) \cdot 10^{-2}$	730^{+170}_{-120}	$(2.36 \pm 0.5) \cdot 10^{-2}$	$1\,080^{+300}_{-200}$

The weighted mean value of $\bar{\alpha}_{100}$, corrected for distorsion (column (*b*)), is

$$\bar{\bar{\alpha}}_{100} = (2.65 \pm 0.37) \cdot 10^{-2} ,$$

and the corresponding

$$\overline{p\beta} = 960^{+180}_{-140} \text{ MeV/c} .$$

If we assume that the event represents the decay in flight of a neutral particle following the decay scheme

$$X^0 \to \pi^+ + \pi^- + Q ;$$

we obtain the Q-value:

$$Q = 220^{+35}_{-30} \text{ MeV} ,$$

from the mean value of $p\beta$ given in Table I *b*.

This value is in accord with that given by THOMPSON *et al.* [3] for the θ^0 [4].

This interpretation of the event is based on the assumption that the fast particle is a π.

We cannot however exclude that it is a proton, due to the lack of an accurate calibration of ionization in this region in which discrimination between π and p is very difficult.

Even on the assumption that the particle is a π other interpretations of the event are possible, e.g. it could represent the production of two π's by a neutron in a nuclear disintegration, or the scattering of a π^+ with loss of practically all its energy, however in this case the absence of any sign of recoil would be rather surprising.

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[4] See also M. M. YASIN: *Phil. Mag.* **45**, 413 (1954).

Example of θ^0 Decay.

M. YASIN

(Reported by M. FRIEDLANDER)

H. H. Wills Physical Laboratory - University of Bristol

The event, shown in the accompanying photograph (Fig. 1) and reported at the Padua Conference by M. FRIEDLANDER, was described by M. YASIN in *Phil. Mag.*, **45**, 413 (1954).

[*Editor's Note.*]

Fig. 1.

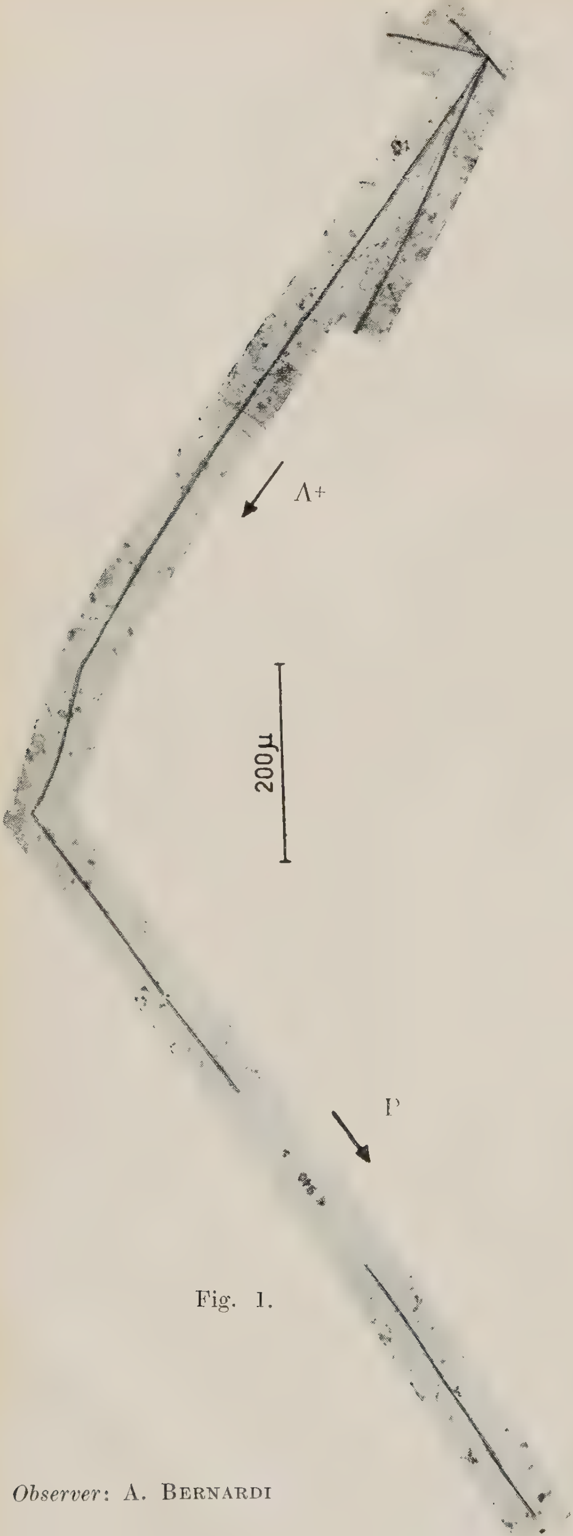

Fig. 1.

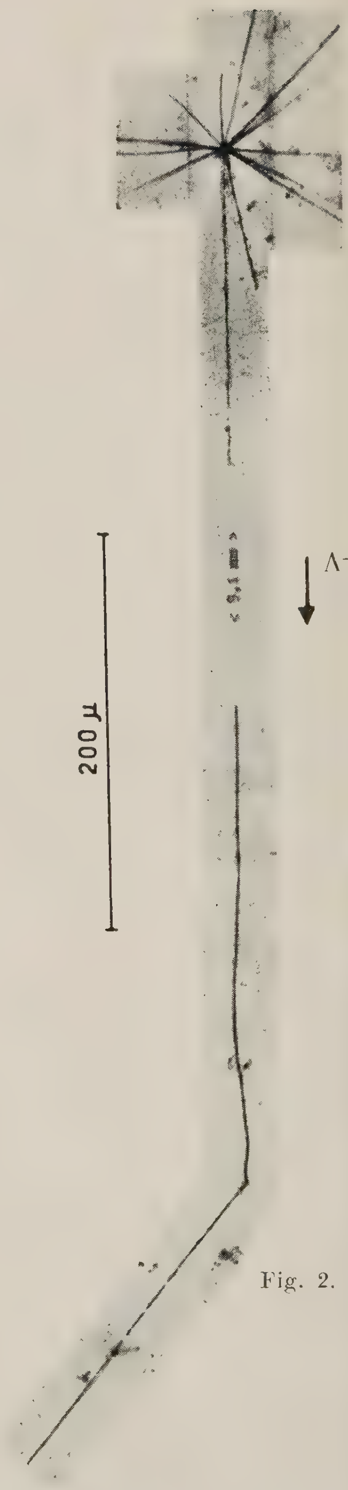

Fig. 2.

Observer: A. BERNARDI

Iperoni carichi e neutri.

Analysis of Charged Hyperons.

M. BALDO, G. BELLIBONI, M. CECCARELLI and B. VITALE

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

During the scanning of the plates of two stacks of stripped emulsions two positive hyperons, one decaying at rest (Y_1^+-Pd_2) and the other in flight (Y_1^+-Pd_3), and a negative hyperon producing a capture star (Y^--Pd_4) have been observed.

The details of these three events together with that of a fourth hyperon which has been previously reported ($Y_1^\pm$-Pd_1) [1] are listed in following Table I. The Q-values given in the last column have been calculated assuming the following modes of decay:

(1) $$Y_1^\pm \to n + \pi^\pm + Q\,,$$

(2) $$Y_1^+ \to p + \pi^0 + Q\,.$$

$Y_1^\pm$-Pd_1: This event was reported on at the Conference of Bagnères [1]. The hyperon after a path length of 3,2 mm decayed in flight giving rise to a minimum ionizing particle which left the emulsion after ~ 4 mm. Measurements on both primary and secondary particle tracks indicate that the primary was of super-protonic mass and that the charged secondary was a π-meson.

Y_1^+-Pd_2 (Fig. 1): In this case, the decay of the heavy particle took place at rest or at least when it had lost practically all of its kinetic energy. A similar event reported by the Milan group [2] shows practically the same range for the secondary proton. The interpretation of this event as the scattering of a single particle has to be excluded by the existence of a sharp discontinuity both in the ionization and the multiple scattering at the point of deflection.

Y_1^+-Pd_3: This event appears as a sharp change in direction of a « grey » particle, 15 mm after its emission from a nuclear disintegration. This change

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Primary							
Particle	Range (mm)	Mass (m_e)	Energy (MeV)	Parent star	Time of flight	β at decay	Angle with secon
$Y_1^{\pm}$-Pd_1	> 3.25	2100 $\pm$ 400	60	11 + 1n	$4.6 \cdot 10^{-11}$	0.23	171°
Y_1^{+}-Pd_2	0.95	1840^{+900}_{-600}	15	5 + 1n	$2.9 \cdot 10^{-11}$	0	—
Y_1^{+}-Pd_3	> 15.00	1900 $\pm$ 250	90	11 + 3n	$14 \cdot 10^{-11}$	0.371 $\pm$ 0.007	26° $\pm$ 3
Y^{-}-Pd_4	9.43	2150 $\pm$ 300	58	27 + 2p	$1.5 \cdot 10^{-10}$	0	—

in direction is accompanied by a change in the grain density of its track (from 47.3 ± 1.3 to 37.2 ± 1.2 grains per 50 μ). The secondary particle comes to rest in the emulsion layers after a range of 28 mm and has been identified as a proton by ionization-range measurements.

The possibility that we are dealing with an example of the stripping of a deuteron, resulting in the emission of a proton with a slightly higher energy, would seem to be excluded by direct mass measurements on the track of the primary particle. A phenomenon of this type, however, would in any case be highly improbable. We observe in our event a change in direction of 26° and a change in energy for the proton of 33 MeV, whereas in the case of the stripping hypothesis we would expect an angular deviation $\leqslant \sim 6°$, and a change $\leqslant \sim 17$ MeV in the proton energy.

The large error in the Q-value is due to the uncertainty in the value of β for the primary particle at the point of the decay. However, in that the calculation was based on the primary ionization, the range of the secondary and the angular deviation, the energy of the proton in the center of mass system is independent of any hypothesis concerning the identity of the primary.

Y^{-}-Pd_4 (Fig. 2): The possibility that the primary particle is a K-meson has

Secondary						
Range (mm)	Mass (m_e)	Identity	Energy (L.S.) (MeV)	Energy (C.M.S.) (MeV)	Q (MeV)	Notes
> 4.3	286 ± 30	π	70	108	131 ± 24	$m_{\pi^\pm} = 273\ m_e$
$.68 \pm 0.02$	$2\,200^{+600}_{-400}$	p	18.5 ± 0.3	18.5 ± 0.3	116.0 ± 2.0	$m_{\pi^0} = 263\ m_e$
8.7 ± 0.6		p	97.7 ± 1.2	20.5 ± 6.1	125 ± 30	

Λ^--star				
Prong No.	Range	Identity	Energy MeV	Notes
1	> 11 mm	(p)	~ 60	
2	$< 2\ \mu$		—	
3	$< 2\ \mu$	—	—	

been excluded by accurate mass measurements which techniques have been previously discussed [3]. The particle is emitted from a nuclear disintegration and on coming to rest produces a star associated with which is a track of a 60 MeV proton together with two short tracks, one of which is probably a recoil.

The presence of the two short tracks would seem to exclude the interpretation of this event as a decay. On the other hand if we assume that it is a decay according to scheme (2), a Q-value of about 300 MeV would be implied. This however would result in a much higher mass for the primary particle than that measured, thus confirming the hypothesis of a nuclear capture.

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Mass and Decay of Charged Hyperons.

A. BONETTI, R. LEVI SETTI and B. LOCATELLI

Istituto di Scienze Fisiche dell'Università - Milano
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

G. TOMASINI

Istituto di Fisica dell'Università - Genova

In this communication the information obtained by the Genoa and Milan groups on charged particles of hyperprotonic mass is reported; some of the events quoted have been described in detail previously [1, 2].

Seven examples of charged hyperons have been found up to now; of them four come to rest in the emulsion, three decay in flight. One of the particles which are stopped in the emulsion gives rise to a slow proton ($GeMi_3$); all the others decay to a light secondary.

The following Table I gives the distribution of the events between glass plates and stripped emulsions:

TABLE I.

	At rest	In flight
Glass plates	$2_L + 1_p$	1_L
Stripped emulsions	1_L	2_L

The subfixes indicate if the secondary is a light meson (L) (or electron) or a proton (p).

Frequency.

The particles which decay at rest have been found during a systematic survey of all particles coming to rest in the emulsion and decaying to a single charged secondary. Owing to the fact that the last part of the track of a

hyperon at rest is rather straight and shows a uniform density, some of the events of this type can be considered at first sight as 2-branch stars; so the number of hyperons at rest which we find is probably underestimated. Anyhow we quote the following figures, Table II, as an indication of the frequency of these particles relative to that of K-mesons found in the same scanning:

TABLE II.

	K- particles	Y-particles at rest
Glass plates	8	3
Stripped emulsions	6	1

A systematic search for hyperons which decay in flight necessitates a study of all 2-branch stars. Those found by us, two during the normal scanning for stars, since the hyperon decays before leaving the emulsion ($GeMi_4$, $GeMi_6$), and the third ($GeMi_7$) by following in an unsystematic way the denser tracks of the 2-branch stars, can represent only a fraction of those existing in the area scanned by us. It is therefore not possible to derive from our results the relative frequencies of Y-particles in flight and at rest.

It is not possible to exclude that some of the particles interpreted as hyperons be some kind of K-mesons decaying in flight; however mass measurements both from scattering and ionization methods favour the interpretation as particles of hyperprotonic mass.

Parent Stars.

In four cases the hyperons are emitted from nuclear disintegrations in the emulsion. The energy of the parent stars vary between wide limits. In three cases the star is generated by a neutral primary; in one case ($GeMi_6$) the hyperon comes out from the nuclear interaction of a σK (see the paper of DI CORATO, LOCATELLI, MIGNONE and TOMASINI, in this issue pag. 270). A detailed study of the stars is in progress.

Mass and Velocity Measurements.

The mass of the primary particles at rest has been determined by the constant sagitta method, using a calibration on protons (DI CORATO, HIRSCHBERG, LOCATELLI, in this issue, pag. 381): a histogram of the values obtained is

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Particle	Reference	Length (mm)	PRIMARY n	β_e	β_d	Mass (m_e)	t_r (s)	T_r
Y-GeMi$_1$	*Nuovo Cimento*, **10**, 345 (1953)	15.76	2	—	rest	2210 ± 250 (α, R)	$2 \cdot 14 \cdot 10^{-10}$	∞
Y-GeMi$_2$	Bagnères Confer. *Nuovo Cimento*, **10**, 1735 (1953)	1.25	1	—	rest	2340 ± 700 (α, R)	$3.45 \cdot 10^{-11}$	∞
Y-GeMi$_3$	Bagnères Confer. *Nuovo Cimento*, **10**, 1736 (1953)	0.9	1	—	rest	2300 ± 800 (α, R)	$2.72 \cdot 10^{-11}$	∞
Y-GeMi$_4$	Padua Meeting	0·6	1		in flight	—	—	—
Y-GeMi$_5$	» »	5.82	6 strip	—	rest	2300 ± 600 (α, R)	$1 \cdot 10^{-10}$	∞
Y-GeMi$_6$	» »	0.6	1 strip	0.31	$0.31 \pm .02$	2700 ± 1350 (α, g)	$7 \cdot 10^{-12}$	∞
Y-GeMi$_7$	» »	4.15	2 strip	0.23	$0.19 \pm .02$	2700 ± 600 (α, g)	$5.6 \cdot 10^{-11}$	∞

shown in Fig. 1 of our paper on K-mesons (BONETTI, LEVI SETTI, LOCATELLI and TOMASINI, in this issue, pag. 227). In some cases ionization measurements have been made and give a substantial agreement with scattering results (see Table III).

The mass of the primary particles decaying in flight has been determined by scattering and ionization methods in the two cases in which measurements were possible (GeMi$_6$, GeMi$_7$). The velocity of emission from the parent star and at the point of decay is deduced by comparison with a calibration on protons. The « constant » of scattering is taken from the curves of VOYVODIC [3] (Molière theory); account has been taken in the evaluation of the errors on $p\beta$ of the spread of 8% in the experimental values of the constant. The results are shown in Fig. 1.

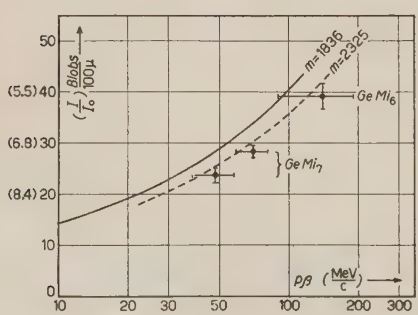

Fig. 1.

The identification of the two measurable light secondaries (GeMi$_6$, GeMi$_7$) has

rons.

Secondary										
n	θ	$p\beta$ (MeV/c)	Energy (MeV)	β_e	β_e^*	p_t (MeV/c)	p^* (MeV/c)	I/I_0	Mass (m_e)	Q (MeV)
1	—	—	—	—	—	—	—	~ 1	—	—
—	—	—	—	—	—	—	—	~ 1	—	—
—	—	—	$18.7 \pm .2$	—	—	—	191 ± 3	ends	proton $(\alpha, R)\ 2\,030^{+530}_{-480}$ $(G, R)\ 1840 \pm 670$	115 ± 3
1	—	—	—	—	—	—	—	~ 1	—	—
14	—	—	—	—	—	—	—	~ 1	—	—
7	32°	204 ± 21	133	0.86	0.77	126	167	1.07 $\pm .02$	—	95 ± 21
5	38°	166 ± 17	104	0.82	0.75	79	160	1.1 $\pm .02$	—	90 ± 20

not been attempted, because the calibration of the stack is not complete; the preliminary values of $p\beta$ and grain density show that the particles are lighter than K-mesons.

The case in which the secondary is a proton has been already discussed in detail [2].

All the available data are collected in Table III, where the symbols have the meaning explained in the *Report on Hyperons*, in this issue, pag. 459, § 5.

Decay Schemes and Q-Values.

The Q-values have been calculated assuming the decay schemes:

$$Y_L^{\pm} \to n + \pi^{\pm} + Q\,, \tag{1}$$

$$Y_p^{+} \to p + \pi^{0} + Q\,. \tag{2}$$

An event similar to $GeMi_3$ has been observed by the Padua group [4]. In their case the secondary proton has a range of 1.680 mm, very close to

that of $GeMi_3$. This fact supports the hypothesis that Y_p^+-events represent 2-body decays. The mass of the primary in the postulated decay scheme (2) can be determined with good precision, being based on a measurement of range, and on masses of well known particles: the value obtained is 2327 ± 3.

If we attribute to this hypothetical particle (indicated as Ω in [2]) the alternative 2-body decay scheme (1), we find that the Q-value should be 110 MeV. Within the large experimental errors, this figure is not inconsistent with the Q-values obtained from $GeMi_6$ and $GeMi_7$, in reasonable agreement with the results of other authors [5] on Y_L-events. However other decay schemes could be adopted: indeed a better knowledge of these decays would be obtained only if some of the light secondaries could be seen coming to rest in the emulsion.

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[5] See references in [2] and the *Report of the Commitee on Charged Hyperons*, in this issue, pag. 448.

Observations on Charged Unstable Particles Heavier than Protons (Hyperons)

C. Castagnoli, G. Cortini and C. Franzinetti

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

1. – Two New Examples.

Two examples of charged unstable particles heavier than protons have been recently found in this laboratory in a stack of Ilford G-5 stripped emulsions, which had been exposed to cosmic radiation on flight No. 17 of the serie of flights made during last June-July in Sardinia [1].

The stack in which they have been found was not surrounded by any absorber except for the thin layer of aluminium of the container and the cardboard and black paper with which Ilford emulsions are usually wrapped.

The two examples are shown in Fig. 1 and 2. The first originates in the emulsion (point A in Fig. 1) at a low energy and comes to rest after a range of 4 080 μ in the same emulsion in which it was generated. Its end is associated with a minimum ionization track which crosses the emulsions for a total length of 12.6 mm and then escapes from the stack.

The variation of ionisation density and of small angle scattering makes certain that this track is due to a particle which is created at A, stops at D and there decays into a charged particle plus an unknown number of neutral ones.

By comparison of measurements of multiple scattering versus range with the constant sagitta method [2] on this track and on a few protons, one gets for the mass the value

$$(M_Y)_{\text{scatt}} = 1840^{+530}_{-430}\ \mathrm{m_e}\ .$$

From measurements on gap length variation versus range [3] we obtained

$$(M_Y)_{\text{gap}} = \sim 3000\ \mathrm{m_e},$$

which makes the interpretation of this event as a particle lighter than a proton unlikely.

The kinetic energy of the heavy particle at the point A of creation is about 40 MeV.

The decay product produces a track which is unfortunately too steep to allow precise measurements. One can exclude however that it is a proton or a heavier particle. If we assume that it is due to a π-meson, then this event is very likely a new example of the hyperons which have been observed by several authors [4-8].

A peculiar characteristic of the present event is that the hyperon is produced in the middle of the emulsion without emission of any other visible track.

The second example (see Fig. 2) originates in a disintegration involving the emission of many charged particles. It is brought to rest after a range of 31.97 mm and then it decays ejecting a charged particle of nearly minimum ionization which again is too steep to allow precise measurements.

Using the multiple scattering methods indicated for particle 1, and also the grain density versus range method, we get for the mass the value

$$(M_{Y})_{scatt} = 2100 \pm 150 \ m_e ,$$

which make it reasonable to assume that this track is due to a hyperon.

2. – Discussion of Available Information on Hyperons.

To our knowledge only eight particles have been reported, which can be confidently attributed to hyperons, in addition to the two described in this paper. Some of the data concerning each of these particles are summarized in Table I.

Mean values for the quantities M_Y and Q_Y can be calculated from these data using the formula

$$\bar{X} = \frac{\sum_i X_i/\mu_i^2}{\sum_i 1/\mu_i^2} ,$$

where each X_i indicates the result of a measurement given with an error μ_i. We obtain:

a) for the mass of the hyperons: $M_Y = 2350 \pm 160 \ m_e$ (*);

b) for the Q of the disintegration: $Q_Y = 117 \pm 3$ MeV.

(*) This average value has been taken over the first nine values of the masses given in Table I as the last one was probably affected by an instrumental error.

Fig. 1

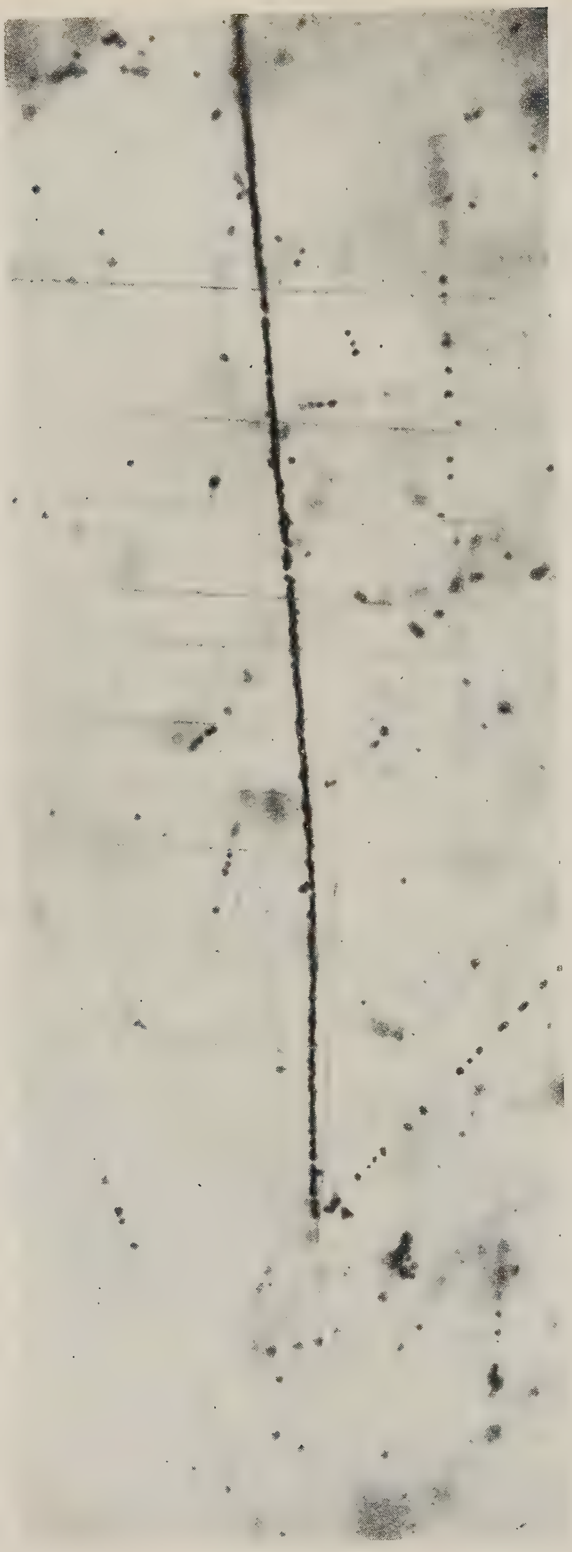

Fig. 2.

TABLE I.

Particle	Primary					Secondary		Suggested mode of decay	Reference
	$p\beta$ at decay (MeV/c)	R (mm)	Mass (m_e)	Q (MeV)	Time of detection (10^{-10} s)	$p\beta$ at creation (MeV/c)	Mass (m_e)		
Y-Ws$_1$	390 ± 70	18.6	$2\,560 \pm 500$	—	0.89	—	—	—	[4]
Y-Ws$_2$	0	3.7	$2\,860 \pm 850$	102 ± 20	0.74	150 ± 35	330 ± 90	$\begin{cases} n + \pi + Q \\ V_1^0 + \pi + Q \end{cases}$	[4]
Y-Bo$_1$	68 ± 15	19.0	$2\,330 \pm 300$	135 ± 24	2.08	160 ± 13	330 ± 60	$n + \pi + Q$	[5]
Y-Pd$_1$	$250 \pm$?	3.25	$2\,100 \pm 400$	131 ± 24	0.18	$110 \pm$?	286 ± 30	$n + \pi + Q$	[6]
Y-GeMi$_1$	0	15.76	$2\,500 \pm 345$	—	2.04	—	—		[7]
Y-GeMi$_2$	0	1.25	$2\,300 \pm 100$	—	0.34	—	—	—	[7]
Y-GeMi$_3$	0	0.9	$2\,320 \pm 700$	115 ± 3	0.27	$140 \pm$?	$1\,840 \pm 670$	$\pi^0 + p + Q$	[7]
Y-Ww$_1$	120 ± 20	2.6	$1\,800^{+700}_{-500}$	120^{+50}_{-30}	0.29	186 ± 30	$1\,500^{+600}_{-400}$	$\pi^0 + p + Q$	[8]
Y-Ro$_1$	0	4.29	$1\,840 \pm 600$	—	0.79	> 50	? (π)	$\pi^+ + n + Q$	[9]
Y-Ro$_2$	~ 60	31.97	2100 ± 150	—	3.00	170 ± 30	? (π)	$\pi^+ + n + Q$	[9]

The nature of the decay product, as pointed out by other authors [4], is firmly established. However, if all the events which we are considering are to be attributed to a unique particle, the available evidence indicates for it two different modes of decay:

$$Y^{\pm} \to \pi^{\pm} + n + Q_Y ,$$

$$Y^{+} \to \pi^{0} + p + Q_Y .$$

3. – The Life Time of Hyperons.

A method has been recently suggested [10,11] and successfully used by several workers to analyze cloud chamber observations on unstable particles in order to get an estimate of their lifetime. In this paragraph we want to show that this method can be extended to be used in connection with the photographic emulsion technique.

Let us consider a number of observations all of one type of particles, decaying in the volume of a stack of emulsions. Let l_r be the length of the r-th track observed in the emulsion from the point of creation of the particle (or of its entry in the emulsion) to the point of decay. Following BARTLETT, let us denote by t_r the time spent by the r-th particle to cover l_r; and by T_r the total time available for the same particle for decay within the emulsion.

The lifetime probability distribution for all the particles of one type is then found to be [11]

$$(1)\qquad P(\tau \mid t_1 T_1, t_2 T_2, \ldots, t_n T_n)\, \mathrm{d}t_1\, \mathrm{d}t_2 \ldots \mathrm{d}t_n =$$
$$= \prod_{1}^{n}{}_r \exp\left[-t_r/\tau\right] \left(1 - \exp\left[-T_r/\tau\right]\right)^{-1} \frac{\mathrm{d}t_r}{\tau} .$$

Photographic emulsions, owing to their large stopping power, provide us with a much higher number of particles which decay at rest, than that obtainable in a cloud chamber. For a particle stopping in the emulsion before decaying T_r must be taken equal to infinity. We shall distinguish between the following three types of events:

a) particles which are brought to rest in the emulsion and then decays. We shall denote them by n_a;

b) particles which decay in flight in the emulsion when they have such a small velocity that they would have been brought to rest in the emulsion, had they not decayed before (n_b);

c) particles which decay in flight in the emulsion and are not to be included in group *b*) (n_c).

Both the events a) and b) are to be associated with an infinite T_r, but distinction must be made between them because they supply us different information on the behaviour of the particles concerned. In the case of an a) event all we know is that a particle has travelled for a time t_r^0, has been brought to rest and has decayed at a time $t_r \geqslant t_r^0$. For b) events t_r is known exactly (*). For events of type c) we can measure both t_r and T_r, the latter depending on the position of the event in the stack of emulsions and on its velocity at the point of decay.

Accordingly, equation (1) must be modified as follows: the factors corresponding to the a) events must be calculated for $T_r = \infty$ and then integrated between t_r and ∞; the factors corresponding to the b) events must be calculated for $T_r = \infty$.

Equation (1) then reads

$$\mathcal{P} = \mathrm{d}t_{n_a+1}\,\mathrm{d}t_{n_a+2} \ldots \mathrm{d}t_n \int\limits_{t_1^0}^{\infty} \mathrm{d}t_1 \int\limits_{t_2^0}^{\infty} \mathrm{d}t_2 \ldots \int\limits_{t_{n_a}^0}^{\infty} \mathrm{d}t_{n_a}\, P(\tau \,|\, t_1 t_2 \ldots t_{n_a}) =$$

$$= \prod_{1}^{n_a}{}_i \exp\left[-\, t_i^0/\tau\right] \prod_{1}^{n_b}{}_k \frac{1}{\tau} \exp\left[-t_k/\tau\right] \mathrm{d}t_k \prod_{1}^{n_c} \exp\left[-t_l/\tau\right]\left[\tau\left(1 - \exp\left[-\, T_l/\tau\right]\right)\right]^{-1} \mathrm{d}t_l \,.$$

It follows that

$$-\ln \mathcal{P} = \sum_{1}^{n_a}{}_i \frac{t_i^0}{\tau} + \sum_{1}^{n_b}{}_k \left(\ln \tau + \frac{t_k}{\tau}\right) + \sum_{1}^{n_c} \left(\ln \tau + \frac{t_l}{\tau} + \ln\left(1 - \exp\left[-\, T_l/\tau\right]\right)\right) + C\,,$$

where C is a constant term including the logarithm of the differential $\mathrm{d}t$. The most probable value of τ is that which makes this expression a maximum. Putting $\partial \ln \mathcal{P}/\partial\tau = 0$ one gets

$$\tau_0 = \frac{1}{n_b + n_c}\left(\sum_{1}^{n_a}{}_i\, t_i^0 + \sum_{1}^{n_b}{}_k\, t_k + \sum_{1}^{n_c}{}_l \left(t_l + \frac{T_l}{\exp\left[T_l/\tau_0\right] - 1}\right)\right). \tag{2}$$

As in BARTLETT's paper, the standard error is provided (at an approximation only valid for small standard errors) by the expression

$$S(\tau) = \frac{\dfrac{\partial \ln \mathcal{P}}{\partial\tau}}{\left[E\left(-\dfrac{\partial^2 \mathcal{P}}{\partial\tau^2}\right)\right]^{\frac{1}{2}}}\,,$$

(*) In the paper presented by AMALDI *et al.* at this congress a graph is given from which t_r^0 can be read when the corresponding range is known (see in this issue, pag, 179),

where E denotes statistical averaging. $S(\tau)$ is then a function having a standard deviation equal to 1. In our case we get

$$(3) \qquad S(\tau) = \frac{\sum_{1}^{n_a}{}_i \dfrac{t_i^0}{\tau} + \sum_{1}^{n_b}{}_k \dfrac{t_k}{\tau} - n_b - n_c + \sum_{1}^{n_c}{}_l \dfrac{t_l}{\tau} + \sum_{1}^{n_c}{}_l \dfrac{T_l/\tau}{\exp\,[T_l/\tau] - 1}}{\left[n_b + n_c - \sum_{1}^{n_c}{}_l \left(\dfrac{T_l}{\tau}\right)^2 \exp\,[-T_l/\tau](1 - \exp\,[-T_l/\tau])^{-2}\right]^{\frac{1}{2}}}.$$

If τ_0, τ_- and τ_+ are the values of τ which make $S(\tau)$ respectively equal to 0, -1 and $+1$, then the most probable value of τ with its standard error is given by

$$\tau = \tau_0 \begin{cases} +(\tau_- - \tau_0) \\ \\ -(\tau_0 - \tau_+)\,. \end{cases}$$

If one plots S as a function of τ (or better of $1/\tau$), τ_0 can easily be found by graphical methods (see Fig. 3).

In order to use this formula for the data given in Table I one should know the values of T_l relative to the events Ws_1, Bo_1, Pd_1 and Ww_1. But none of them was available to us. However as in all these cases except Ws_1 the momentum of the hyperon at the point of decay would not have allowed the particle to escape from the emulsion unless the decay had happened within a few millimeters from the edge of the stack, we assumed that Bo_1, Pd_1 and Ww_1 were in the b) group.

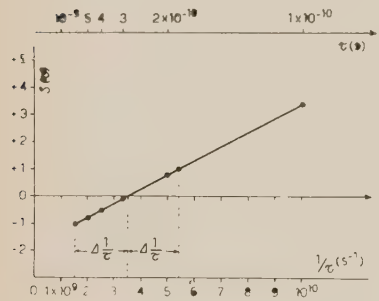

Fig. 3.

For Ws_1 knowing its observed range before decaying and considering the size of the plates used for nuclear research, we can say that T_l is certainly within the limits

$$2\cdot 10^{-10} \leqslant T_l \leqslant 10^{-9}\ \text{s}\,.$$

The calculation of τ_0 can be done assuming alternatively these two limiting values. Taking into account this source of uncertainty and the statistical error (3), one finds for the mean life of the hyperons

$$1/\tau_0 = (0.35 \pm 0.22)\cdot 10^{10}\ \text{s}^{-1}\,,$$

which corresponds to

$$\tau_0 = (2.9^{+4.8}_{-1.1})\cdot 10^{-10}\ \text{s}\,.$$

In the calculation given here we have not taken into account that there is an experimental bias which favours the events of hyperons decaying at rest in comparison with those decaying in flight, the latter being more difficult to detect. Therefore the value given above has to be considered as an upper limit of the mean life; one can however easily recognize that the correct value of τ_0 can not be lower by a large factor.

4. – Suggested Procedure in Publishing the Results.

The importance associated with these and other new unstable particles, together with their low frequency of occurrence, makes it necessary to try to obtain as much information as we can by comparing results obtained by different people under different experimental conditions.

In order to make possible more precise measurements of the lifetimes of unstable particles with the method considered in this paper, we suggest that any publication concerning new examples of unstable particles should supply the following information (in addition to any other):

1) Values of the time during which a particle has been observed before decaying (t_r);

2) Values of the available time (T_r) which the particle would have spent in the emulsion if it had not decayed.

* * *

It is our pleasant duty to thank Prof. Amaldi, for his help given to us in the discussion of the method for measuring the lifetime and for continuous assistance during the work.

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Results on Neutral V-Particles.

M. CECCARELLI, M. GRILLI and B. VITALE

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

In following back about three hundred π^- and π^+ mesons from the end of their range towards their origins, we have found four two-prong events, composed of a π^--meson and another singly charged particle.

The details of these events have been listed in Table I.

TABLE I.

Particle	Tracks of the V			Characteristics of the decay			Q (MeV)	Mass (m_e)
	Identity	Range (μ)	Energy (MeV)	φ	θ	p (MeV/c)		
V_1^0-Pd_1	π^- (σ)	$26\,800 \pm 600$	43.0 ± 1.0	$69^\circ \pm 2^\circ$	76°	342	34.5 ± 2	$2\,180 \pm 4$
	p (assumed)	$6\,150 \pm 150$	40.2 ± 1.0					
V_1^0-Pd_2	π^- (σ)	$2\,830 \pm 150$	11.3 ± 1.0	$103^\circ \pm 2^\circ$	120°	180	14.9 ± 1.5	$2\,143 \pm 3$
	p (assumed)	1890 ± 100	20.1 ± 1.0					
V_1^0-Pd_3	π^- (σ)	$24\,100 \pm 800$	39.7 ± 1.8	$93^\circ \pm 2^\circ$	86°	280	39.2 ± 1.5	$2\,190 \pm 3.0$
	p (assumed)	$2\,800 \pm 200$	25.3 ± 1.1					
V_1^0-Pd_4	π^- (σ)	$6\,100 \pm 100$	17.9 ± 0.2	$130^\circ \pm 2^\circ$	90°	300	38.8 ± 2.0	$2\,189 \pm 4.0$
	p (assumed)	$12\,900 \pm 400$	61.2 ± 1.1					

φ=angle between π^- and « p probable » in the laboratory system.
θ=angle between the directions of the motion of Λ^0 and π^- in the center of mass system.
p=momentum of Λ^0 in the laboratory system.

Both particles of every V-event come to rest in the emulsion layers, however we were not able, because of their track length or large dip, to identify with certainty the track associated with the π^--meson.

We have therefore assumed that the track was produced by a proton, and have calculated the Q-value on this basis. The errors listed for the Q-values have been calculated as the sum of the absolute value of the individual errors in the measurements.

The Q-values for three of these events ($Q_1 = 34.5 \pm 2$; $Q_3 = 39.2 \pm 1.5$; $Q_4 = 38.8 \pm 2.0$ MeV) are all consistent with a Q-value ~ 37 MeV.

The anomalous event (number 2 in the table: $Q_2 = 14.9 \pm 1.5$) may be explained as resulting from a nuclear disintegration or as the decay of a completely different particle (for example the V-dineutron of CHESTON and PRIMAKOFF (*): V-dineutron $= p + n + \pi^- + 130$ MeV).

Two additional events, in which a π^+-meson and a singly charged particle were associated, have been observed. These have been assumed to be the result of a nuclear disintegration. We have calculated the Q-values of these events in order to estimate the background Q-values for Λ^0-particles. The values so calculated are $Q'_1 = 0.5 \pm 0.5$, $Q'_2 = 26 \pm 3$ MeV.

The V-particles observed in this investigation were generally emitted in the forward direction with respect to the vertical and with energy values ranging from 25-50 MeV.

(*) W. CHESTON and H. PRIMAKOFF: *Phys. Rev.*, **93**, 908 (1954).

Report on the Bristol Group Work on Hyperons.

M. FRIEDLANDER

H. H. Wills Physical Laboratory - University of Bristol

Charged Hyperons. (Bristol group.).

Of those reported, two were found by direct scanning and these are fully reported in the *Philosophical Magazine*, April, 1954. One hyperon has been found by following grey tracks from stars (see C. DAHANAYAKE *et al.*, in this issue, pag. 250), and one by tracing other tracks from a star from which a K-meson had already been found. Those hyperons identified by grain density and scattering, are discussed separately, in the account of the work of FOWLER and PERKINS (*).

V⁰-Decays. (FRIEDLANDER, KEEFE, MENON, MERLIN).

This work is fully described in the *Philosophical Magazine*, May, 1954. By following back π-mesons, 20 two-prong events have been found, in which the other particle could be identified as a proton. In eleven cases, the proton also ends in the emulsion. Assuming that these events represent the decay of neutral particles into a proton and a negative π-meson, Q-values have been calculated. There is a general spread in the Q-values, from 0.5 MeV to over 80 MeV, but there is a very pronounced peak in the 37 MeV region. In the interval 35.6-38.4 MeV, there are 10 events, in nine of which both the proton and π-meson come to rest in the stack. The weighted mean Q-value for these 10 events, is 36.92 ± 0.22 MeV. A very careful calibration has been made of the stack used, and it has been necessary to extrapolate the range-energy relation. This procedure is fully described in the *Philosophical Magazine*, May, 1954. The data on the events is given in the Table II of the Report of the Committee on neutral V's, in this issue, pag. 463.

(*) P. H. FOWLER and D. H. PERKINS: see in this issue, pag. 236.

Evidence for Nuclear Interaction of a Charged Hyperon Arrested in Photographic Emulsion.

R. H. W. JOHNSTON and C. O'CEALLAIGH

School of Cosmic Physics, Dublin Institute for Advanced Studies - Dublin

The paper has been published in *Phil. Mag.*, **45**, 424 (1954).
The event is shown in the accompanying photograph (Fig. 1).

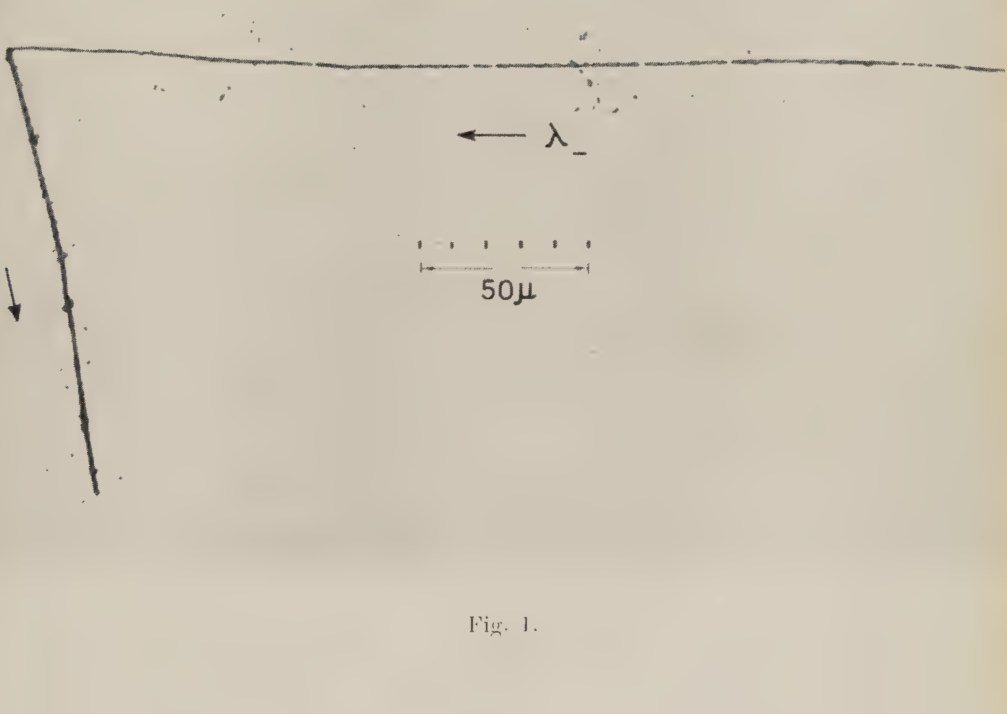

Fig. 1.

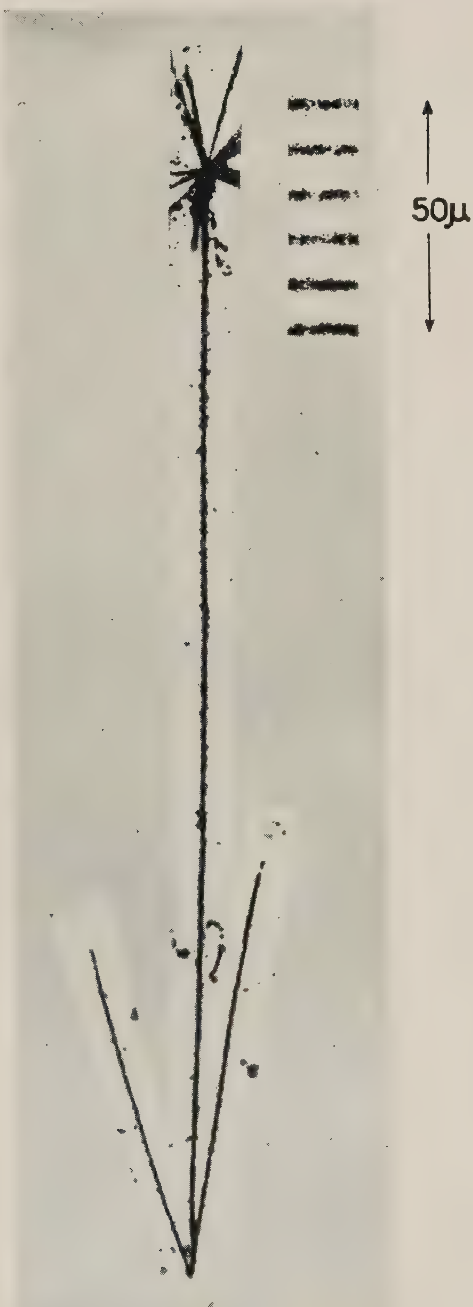

Fig. 1.

Frammenti nucleari eccitati.

An Unstable Heavy Fragment.

K. Gottstein

Max-Planck-Institut für Physik - Göttingen

I just want to give a brief description of the event shown by Fig. 1. A black track showing a slight tapering comes out of a star of type $27+4p$. It is 260 μ long, and a slight scattering towards the end indicates, apart from the tapering, that the particle has come to rest. From the end point emerge two tracks having the typical appearance of those of α-particles. They, in their turn, come to rest after 75 and 103 μ, respectively. This means energies of about 12 and 14 MeV.

This fact and the appearance of the track of the fragment make it likely that the latter was a Be nucleus. Under this assumption there exist two possible ways for the interpretation of the event:

$$^{9}\mathrm{Be} \to {}^{4}\mathrm{He} + {}^{4}\mathrm{He} + \mathrm{n} + Q\,,$$

$$^{9\,\mathrm{or}\,10}\mathrm{Be} \to {}^{3\,\mathrm{or}\,4}\mathrm{He} + {}^{3\,\mathrm{or}\,4}\mathrm{He} + \mathrm{n} + \mathrm{n}\,(+\,\mathrm{n})\,(+\,\mathrm{n}) + Q^*\,.$$

^{8}Be is out of the question since the time of flight of the particle is $\sim 10^{-11}$ s, whereas the lifetime of ^{8}Be is much shorter. Under the first assumption one obtains from the energy and momentum balance

$$Q = 195 \pm 3 \text{ MeV}\,.$$

Under the second

$$Q^* > 104 \text{ MeV}\,.$$

Q is larger by about 20 MeV than the value to be expected if the event is to be explained as the delayed disintegration of a nucleus containing a Λ (V_1^0) particle. Then the energy released should be ~ 175 MeV as found by other workers. If one does not want to introduce another level of excitation present, one has to assume that the second scheme includes the correct interpretation. Since under these conditions one obtains solely a lower limit for Q^*, it is not possible to say anything about the binding energy of the Λ-particle.

Two Unstable Fragments.

M. GRILLI, B. SECHI and G. T. ZORN

Istituto di Fisica dell'Università - Padova
Istituto Nazionale di Fisica Nucleare - Sezione di Padova

During the normal scanning of photographic emulsions exposed during the Sardinian expedition, two events were observed, in which a « heavy » nuclear fragment was ejected from a nuclear disintegration, came to rest and disintegrated producing a star. A photograph of the first event (F_1) is presented in Plate I. The two events have been analysed in some detail and the results appear in Tables I and II.

TABLE I. – *Unstable fragments and their parent stars.*

	Parent star	Range (μ)	Z	t (s)	θ	Notes
F_1	10+7p	170±5	4	$5.2\cdot10^{-12}$	15°	For the calculation of t we have assumed that $F_1 = {}^9_4Be$ and that $F_2 = {}^7_3Li$.
F_2	11+1p	9±2	3	$1.4\cdot10^{-12}$	130°	

Z=charge of the fragment θ=true angle between the primary and the fragment t=time of flight

Referring to Table I we note that these unstable fragments were ejected in nuclear disintegrations of considerable energy (10 and 2.5 GeV), in which occurred the production of at least one pion and the possible production of heavy mesons. With this possibility in mind, all the tracks, with the exception of particles at minimum ionization and three particles emitted at a very large angle with respect to the emulsion plane, were followed to the end of their range or until they left the stack. However no evidence for the co-production of a heavy meson or hyperon in either event was found.

Estimates of the charge of the fragments have been made by the comparison of their tracks with those of α-particles whose ranges terminated in the emulsion. In this way F_1 has been identified as a Be nucleus. Because

Fig. 1.

Observer: V. CHIAROTTI

of the short range of F_2 (9 μ) it has not been possible to identify the charge of the fragment and, therefore, one can not exclude the possibility that this event may have been produced by the capture of a pion or a heavy meson.

TABLE II. – *Disintegrations of the fragments.*

Fragment	Track No.	1	2	3	4	Notes
F_1	Identity	p (probable)	p (probable)	p	p	The four tracks are not coplanar.
	Range (μ)	105	670	1 520	17.900	
	Energy (MeV)	3.8	10.5	17.0	80.0	
F_2	Identity	p	d	p		The three tracks are not coplanar. The angle between track 3 and the plane defined by tracks 1 and 2 is 27°.
	Range (μ)	4 600	1 400	800		
	Energy (MeV)	32.5	21,5	11.7		

Another estimate of the charge of the fragments may be obtained by summing the charges of the secondary particles, the identity of which were determined by gap-length range measurements or scattering-range (constant sagitta) measurements. This results in a charge of $Z = 4$ and $Z = 3$ respectively for the two fragments.

For the calculation of the times of flight we have assumed that these fragments were stable isotopes, $F_1 = {}^9Be$ and $F_2 = {}^7Li$, and we have obtained the values $5.2 \cdot 10^{-12}$ s and $1.4 \cdot 10^{-12}$ s respectively.

Events of the type reported here have been attributed to the delayed decay or capture of an unstable particle produced in the parent disintegration. Three unstable particles which have been proposed are: the π-meson, the K-meson and the Λ^0-particle.

From the experimental evidence thus far reported one cannot exclude the possibility of some delayed disintegration caused by pions or by K-mesons, however, from theoretical considerations on the lifetime of unstable fragments, which were discussed by CHESTON and PRIMAKOFF [1], the delayed capture of these would seem to be much less probable.

On the other hand the hypothesis of the decay of a Λ^0 present as an « excited » neutron in the fragment explains quite satisfactorily the experimental data and is consistent with theoretical predictions. The various decay schemes

that have been proposed are listed below, and will be discussed in the light of the experimental evidence now available:

$$\Lambda^0 \to p + \pi^- + \sim 37 \text{ MeV}, \tag{1}$$

$$\Lambda^0 \to n + \pi^0 + \sim 40 \text{ MeV}, \tag{2}$$

$$\Lambda^0 + p \text{ (or n)} \to n + p \text{ (or n)} + \sim 175 \text{ MeV}. \tag{3}$$

The three examples [2] that have been observed, in which a π-meson is emitted in the disintegration of the fragment, are satisfactorily explained by the first scheme of mesonic decay. The Q-values associated with these events lie between 30 and 40 MeV.

The remaining 8 examples [3] are characterized by the absence of π-mesons emitted during the disintegration of the fragment, and by the presence of a relatively large number (six) of high energy protons ($\geqslant 30$ MeV). This latter fact makes very improbable an explanation based solely on scheme (1), where the π-meson is absorbed in the fragment, for, wereth is the case, a percentage of only $4.9 \pm 1.5\%$ of the events should have had high energy protons associated with them (MENON *et al.* [4]).

To explain these 8 events we may, however, consider schemes (2) and (3).

In scheme (2) the absorption of a π^0-meson (assuming that it is captured by a pn pair [5]) would result in the frequent emission of a high energy proton, as is observed. An explanation of these events based on this scheme alone, however, would not seem to be consistent with the experimental facts in that the high disintegration energy of the fragments, and the frequency of high energy protons from the disintegrations require that it should always be absorbed [6].

It must be added, however, that even though no disintegration of very small energy ($\ll 35$ MeV) have been observed, these may have escaped observation. The decay scheme (2) cannot, therefore, be excluded.

An important fact that may be noted is that the 8 events, in which no mesons appear, may be quite satisfactorily explained by the scheme (3) alone, i.e. the non-mesonic decay.

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Osservazioni con camera di Wilson.

Report on the Cloud Chamber Work in Some American Universities.

M. Annis (*)

Massachusetts Institute of Technology - Cambridge (Mass.)

H. S. Bridge, H. Courant, B. Dayton, H. C. DeStaebler, B. Rossi, R. Safford and D. Willard (*Massachusetts Institute of Technology - Cambridge, Mass.*).

S-**Particles.** – The data were taken with a multiplate cloud chamber containing either lead plates 0.25 inches thick or brass plates 0.50 inches thick.

Up to the present, 40 S-particles have been observed. The fraction of these particles with associated γ-rays is observed to be 18%. Of these 40 S-particles, the decay products, in 20 cases, leave the chamber before traversing 60 g cm^{-2} of Pb equivalent. These events are classified as S-events, since the secondaries, in each case, traversed at least 15 g cm^{-2} of Pb at minimum ionization. In none of the above cases associated soft showers were observed. The other 20 cases are considered particularly interesting because either *a*), the range of the charged decay product is greater than 60 g cm^{-2} of Pb, or *b*), the charged decay product stops in the chamber, or *c*), there is an electron cascade associated with the event.

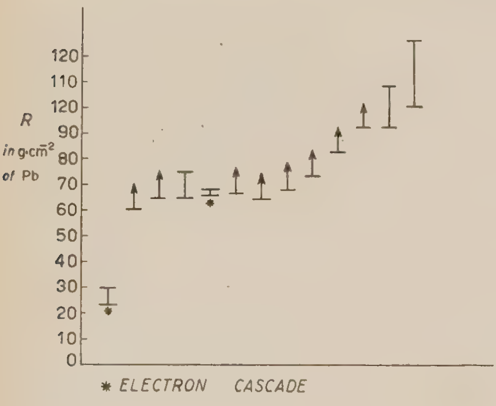

Fig. 1.

Fig. 1 summarizes the information for all charged decay products which either stop in the chamber or have ranges greater than 60 g cm^{-2} of Pb. The ordinate of this graph is the range of the charged secondary; the solid horizontal dashes indicate the range limits, and the arrows indicate that the

(*) Now at Padua University.

secondary left the chamber before stopping. It can be seen from the figure that in two cases where the range is well defined, (and different in the two cases) there was an associated electronic cascade. In the 7 other cases where an electronic cascade was observed, the charged secondary left the chamber before stopping. The minimum range of the charged secondary, in these cases, was from 0 to 50 g cm^{-2} of Pb. The observed soft showers were probably produced by γ-rays, since in 5 out of 9 cases a non-ionizing link was observed before the shower began. These showers had a total number of electrons between 2 and 9.

The γ-rays were usually emitted nearly opposite to the charged secondary; however, in at least 5 cases the cascade was clearly *not* at 180° from the charged secondary.

A statistical analysis was made of the scattering angles in Pb of the charged secondaries from 18 S-particles. Assuming that all secondaries have a unique momentum, this momentum is 250 ± 30 MeV/c if the secondary is a μ-meson, and 265 ± 30 MeV/c if the secondary is a π-meson.

An Unusual Event. – We have observed a most unusual event in the MIT multiplate cloud chamber. A slow, heavy particle stops in one of the brass plates of the chamber and produces three electron cascades. There is no other visible product. The showers diverge at wide angles and appear to be initiated by photons. Lower limits for the energies of the three showers are about 20, 130 and 590 MeV. More probable values are 160, 220 and 925 MeV.

One might perhaps explain this event in terms of known particles, by assuming that the stopped particle is a negative heavy meson which undergoes nuclear absorption, thus transforming practically all its energy into γ-rays. However, the masses of known heavy mesons do not appear to be quite sufficient to account for the observed energy release. If the event is a decay process, the conservation of momentum requires that a fourth unseen particle was emitted. In this case the lower limit for the total energy release is about 1200 MeV. This large value raises the question as to whether the event may be interpreted in terms of an annihilation process.

C. M. YORK, Jr., R. B. LEIGHTON and E. K. BJORNERUD (*California Institute of Technology - Pasadena, Cal.*).

An analysis of 103 charged V-decays was presented. These events have been observed with a double cloud chamber operated at 1 750 m altitude.

The events in the upper chamber appear to have markedly different properties from those in the lower. The particles in the upper chamber have measured properties which are in every respect consistent with those of the K-meson. Their lifetime is in the range $5\cdot10^{-10}$ to $2\cdot10^{-8}$ s; their mass is

~ 1000 m_e; their transverse momentum distribution is consistent with a three-body decay scheme; the momentum in the center of mass system of their charged decay products is also consistent with three-body decay; and their frequency of production is greater than 0.4 percent of the total number of shower particles observed.

On the other hand, the particles observed in the lower chamber have a lifetime in the range 10^{-11} to $3\cdot10^{-10}$ s; their transverse momentum distribution is consistent with a two body decay scheme; their frequency of production is greater than 0.8 percent of the total number of shower particles; they are observed with approximately one third of the frequency of Λ^0-particles; and they apparently can be produced in meson-nucleon collisions. The majority of the particles in the lower chamber are tentatively identified as charged hyperons with the aid of two cases which appear to have proton secondaries. The proposed decay scheme is

$$V_1^+ \to p + \pi^0 + Q$$

and in order to fit all of the data, the alternate mode of decay, $V_1^+ \to \pi^+ + n + Q$ must be introduced. The Q-value is estimated to be $\lesssim 125$ MeV.

R. W. THOMPSON, J. R. BURWELL, H. O. COHN, R. W. HUGGET, C. J. KARZMARK and Y. B. KIM (*Indiana University - Bloomington, Ind.*).

The Indiana group reported that they have found nothing since the January 1954 Rochester meeting which would materially modify the report given there.

As described in that report, there are 19 cases of V-events which are compatible with:

$$\theta^0 \to \pi^+ + \pi^- + (214 \pm 5)\ \text{MeV}\,,$$

i.e. $M_{\theta^0} = 966 \pm 10$ m_e.

There are two anomalous V-events which cannot be described as the usual Λ^0 or θ^0-decays.

Two charged V-events have been observed (both positive primaries) which are compatible with:

$$K_\mu \to \mu + \nu\,.$$

The (computed) momenta of the μ, in the two cases, are 223 ± 6 MeV/c and 235 ± 15 MeV/c.

A Review of Anomalous V^0-Decays.

J. P. Astbury (*)

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

Two types of V^0-particle are now well established: the Λ^0- and θ^0-particles [1]. It was generally felt at the Bagnères-de-Bigorre Conference that these two alone could not account for all the neutral decay events. I propose to discuss the published data on the anomalous events, by which I mean V^0-events which are apparently inconsistent with the Λ^0 or the θ^0-decay process.

I will call V_1^0-events those which can be interpreted by the process

$$V_1^0 \to p + \pi^- + Q.$$

Similarly V_2^0-decays will be defined by

$$V_2^0 \to \pi^+ + \pi^- + Q\,.$$

The Λ^0 and θ^0-decays are then special cases of V_1^0 and V_2^0-decays, with Q-values of about 40 and about 210 MeV respectively. The V_1^0 and V_2^0 decay processes defined above have been assumed in deriving the Q-values which will be quoted below. But it should be noted that if, for example, V_2^0 decays other than θ^0-decays are assumed to exist, there is no evidence in favour of their secondary particles being π rather than μ-mesons; moreover, as we shall see, there is no evidence in favour of a two-body V_2^0-decay scheme apart from θ^0-decay; however we assume a two body decay in quoting the Q-values given below.

In the distribution of Q-values for events interpreted by Leighton *et al.* [2] as two body V_1^0 decays there is a secondary peak at about 75 MeV; the authors report that some of their examples of V_1^0 decay have Q-values definitely higher than 40 MeV. Other groups have not found evidence in support of the postulated existence of a high Q V^0-decay.

(*) Now at University College, London.

Most groups [2-5] have found some events which cannot be V_1^0-decays and which interpreted as V_2^0-decays yield Q-values much lower than 200 MeV, thus appearing inconsistent with the θ_0-decay process. Some of these could be identified with a third type of V_0-decay, tentatively suggested by LEIGHTON *et al.*:

$$V_3^0 \to \tau^{\mp} + \pi^{\pm} + Q \,.$$

(In the numerical calculations referred to in the subsequent discussion we have assumed that the secondaries of V_3^0 are τ and π-mesons; but again these should be taken only as representative values. The light particle could equally well be a μ-meson; the heavier particle could be any K-meson, viz any particle with mass intermediate between that of a proton or a π-meson).

The V_3^0-decay process was postulated by LEIGHTON *et al.* because, among 74 negative secondary particles for which mass estimates could be made, one was found which lay in the range $450 \leqslant m_- \leqslant 1000\ m_e$. The mass estimate for the associated positive particle was $m_+ \leqslant 350\ m_e$. It will be shown later that, even ignoring the mass estimate for the negative particle, the event can not be reconciled with either Λ^0 or θ^0-decay.

LEIGHTON *et al.* pointed out that it is possible, though unlikely, that the event was the decay of a charged V-particle travelling upwards. They noted that in the same experiment they observed 18 $V^{\pm}$-particles, none of which was travelling upwards, and all of which were clearly associated either with a penetrating shower or with a nuclear interaction in the lead plate between their chambers.

It was originally thought that the kinetic energy of the assumed secondary particle in the centre of mass system was much too high to be consistent with a charged V-decay, but a recent recalculation has shown that the inconsistency is not as marked as at first appeared [6].

All the anomalous events summarized above were found in cloud chambers operated in a magnetic field. In considering the significance of these events we have to remember that the errors in measurement of the magnetic curvature are, on the most optimistic evaluation, normally distributed. More than a thousand V^0-particles have now been observed in magnet chambers, and several hundreds of secondary tracks have been measured. Thus if the data consist exclusively of Λ^0 and θ^0-particles we should nevertheless expect to find a few examples apparently grossly inconsistent with Λ^0 or θ^0-decay. In these circumstances it is difficult to establish, on the evidence of a single photograph, the existence of a new type of V^0-decay. We should rather consider together all the published data on anomalous events, and endeavour to detect characteristic common features.

The published data from four groups working with cloud chambers in magnetic fields are presented in Table I.

TABLE I *Anomalous* V^0-*Decays* (*).

	REFERENCE	φ	p_1 (10^8 eV/c)	p_2 (10^8 eV/c)	α (**)	p_t (10^8 eV/c)	Q (MeV)		
							Λ^0	θ^0	V_3^0
1	LEIGHTON *et al.* 1953 fig. 16	64°	+1.9	2.1	−0.07	1.06	—	70	60
2	ARMENTEROS *et al.*, 1953 [7] Ev. 13	61° ± 2°	$+1.24^{+.54}_{-.29}$	$-1.76^{+.29}_{-.21}$	−0.23	0.73	64	—	61
3	BARKER 1954, Event 13	14°	+5.8	− 8.0	−0.16	0.82	—	50	64
4	BARKER 1954, Event 12	19°.5	+6.6	−11	−0.26	1.40	—	129	88
5	ASTBURY 1953 [8], Event PN 301	41° ± 3°	+0.7 ± .13	$-6.9^{+1.4}_{-1.0}$	−0.88	0.46	≫100	153	41
6	NEWTH 1953 [9]	15° ± 1°	$+5.0^{+1.7}_{-1.0}$	$-5.0^{+1.7}_{-1.0}$	0.00	0.65	156	27	80
7	BARKER 1954, Event 1	85°	−1.2	+ 3.0	+0.68	1.08	—	114	52
8	BALLAM *et al.* 1953, Event 80206	32.5° ± 1°	−2.6 ± 0.4	+ 3.25 ± 1	+0.12	0.81	81	46	54
9	BALLAM *et al.* 1953, Event 79166	36.5° + 1°	−0.87 ± 0.15	+ 3.7 ± 1	+0.66	0.43	—	63	< 20
10	LEIGHTON *et al.* 1953, Event 25686	53° ± 1°	−0.67 ± 0.07	+ 3.75 ± 1	+0.76	0.48	10	—	< 20
11	LEIGHTON *et al.* 1953, Event 19955	19°.0	−3.0 ± 0.25	+ 5.0 ± 0.5	+0.26	0.62	72	—	33
12	LEIGHTON *et al.* 1953, Event 28167	114° ± 1°	−0.77 + 0.07	+ 8 ± 1.5	+1.06	0.73	81	290	> 100
13	LEIGHTON *et al.* 1953	—	—	—	+		—	110	∼ 60
14	LEIGHTON *et al.* 1953	—	values not	available	+	—	—	110	∼ 60
15	LEIGHTON *et al.* 1953	—	—	—	—	—	—	110	—

(*) Since this Table was prepared I have received from Professor R.W. THOMPSON the measurement on two events: R 439 ($p_+ = (8.6 \pm 0.4)\cdot 10^8$ eV/c, $p_- = (4.9 \pm 0.5)\cdot 10^8$ eV/c, $\varphi = 19°.7 \pm 0°.1$) and No. 328 ($p_+ = 2.5\cdot 10^8$ eV/c, $p_- = 3.9\cdot 10^8$ eV/c, $\varphi = 29°.6$). The first of these is of particular interest as it was obtained in the new Indiana chamber, in which the maximum detectable momentum is considerably higher than those of the chambers represented in Table I. The Q-value for the V_2^0 process is 86 ± 6 MeV; for the V_3^0 process it is 65 MeV. For the second event the Q-values are 50 MeV for a V_2^0 decay and 42 for a V_3^0 decay. I am very much obliged to Professor THOMPSON for sending me a copy of his communication to the Rochester conference in 1954. I have also heard that FRETTER and his colleagues are relatively sure that one of the events in their new chamber is an anomalous decay. It is not coplanar with any reasonable source; both the decay particles are light particles and the measured Q-value for a V_2^0-decay is 87 ± 20 MeV.

(**) α is defined following R. ARMENTEROS, K. H. BARKER, C. C. BUTLER and A. CACHON in *Phil. Mag.*, **42**, 1113 (1951).

There are known to be other anomalous events, but measurements are not at present available.

Of the two secondary momenta, given in columns 3 and 4 the first, p_1, is taken as the momentum of the lighter particle in interpreting the events as V_3^0-decays. The Q-values interpreted as two body decays according to the three decay processes defined above, V_1, V_2 and V_3, are given in the final columns. The α and p_t values are given in columns 5 and 6.

Errors in the Q-values are not given. We have to assume the possibility of large errors in momentum measurements and in these circumstances estimates of errors in Q-values are unreliable. Considering the data a whole we see that most of it is obviously not produced by high Q V_1^0-particles. (It should however be noted that other high Q events have been observed by LEIGHTON, which are not described in the table because the measurements have not been published; it is also possible that other groups have one or two apparently high Q events, which are nevertheless not inconsistent with the normal value of about 40 MeV; but no group, other than LEIGHTON *et al.*, have found any considerable evidence in favour of a high Q V_1^0-decay).

It is noteworthy that eleven out of the 15 events represented in Table I have Q-values, if interpreted as V_3^0-decays, between 30 and 90 MeV. On the other hand there appears to be no evidence in favour of a V_2^0-decay with a unique Q-value below 200 MeV. Several, though not all, of the events have V_2^0 Q-values below 80 MeV, and may therefore be examples of the hypothetical decay process $\tau^0 \rightarrow \pi^+ + \pi^- + \pi^0$ [10, 11].

Recent observations [12-14] of what appears to be an alternative form of $\tau^{\pm}$-decay, $\tau^{\pm} \rightarrow \pi^{\pm} + 2\pi^0$ provoke renewed speculation about the probability of finding also τ^0 decays. But if a τ^0 particle exists the life time for the decay $\tau^0 \rightarrow 2\gamma$ may well be much shorter than for $\tau^0 \rightarrow \pi^+ + \pi^- + \pi_0$ [11, 15].

In this connection one event, no. 8, deserves special attention. The authors quote, without comment, measurements of the angles, θ_+ and θ_-, made by the secondary tracks to the assumed direction of the neutral particle. Coplanarity measurements are not explicitly given. It is possible that the V^0-particle came, not from the assumed origin but from some other unidentified source; and the authors do not take the angle measurements into account in calculating the Q-value for a two body V_2^0 decay; we have followed their example and ignored the angle measurements in deriving the V_3^0 Q-value quoted in Table I. If the angle measurements are taken into account the event appears rather unlikely to be a two-body decay; it would be consistent with the decay of a τ^0-particle.

It is however unlikely that the bulk of the events represented in Table I can be τ^0-decays. An unbiassed selection of τ^0-decays would yield, on average, an equal number of positive and negative values of α. The events in Table I are certainly not an unbiassed selection. They are selected against a back-

ground of Λ^0-decays. Thus they are biassed against positive values of α by the need to exclude events which might be interpreted as Λ^0-decays. If these anomalous events represented τ^0-decays we should expect to find predominantly negative values of α. In fact we find 8 positive values and 5 negative. With such small numbers we cannot exclude the possibility of a statistical fluctuation; but we know that in the data of LEIGHTON *et al.* there are other events with positive values of α; thus we have at least a preliminary indication that most of the events in the table represent charge and mass asymmetrical decays.

If the indication that we are dealing with asymmetrical decays is accepted as significant there are three possible explanations:

1) The events are mainly high Q V_1^0-decays; this has already been discussed and shown to be unlikely.
2) The events are mainly seriously distorted Λ^0-decays.
3) Some charge asymmetrical particle other than the proton is involved.

An indication that such a particle may exist is given by the recent results of GREGORY *et al.* [13]. If a decay of the type $V_3^0 \to K^+ + (\pi^- \text{ or } \mu^-)$ exists, unaccompanied by an equal number of decays of the type $V_3^0 \to K^- + (\pi^+ \text{ or } \mu^+)$ it would be difficult to detect against a background of Λ^0-decays. It would account for the asymmetrical distribution of θ^* noted for assumed Λ^0-decays by FRETTER *et al.* [16] and ARMENTEROS [17], and for the shape of the mass histogram obtained by LEIGHTON *et al.* (see comments by ARMENTEROS and by LEIGHTON *et al.*).

A rather untidy feature of this third explanation is that the assumed heavy mesons involved do not appear to be exclusively positive. Indeed in the prototype event the heavy meson is negative. The events with negative α are however worth special attention for the following reasons: 1) they are less likely to be distorted Λ^0 decays; 2) if charge symmetrical decays are involved these should represent about half of the sample; 3) events with positive α which are apparently inconsistent with Λ^0 or θ^0-decay will, if interpreted as V_3^0-decays, tend to yield an artificial peak in the neighbourhood of 60 MeV [18].

Four of the six events with $\alpha \leqslant 0$ can be interpreted as τ^0-decays; but two have Q-values, interpreted by the V_2^0 scheme, which are considerably greater than 80 MeV. All of the events are, within the errors of measurement, consistent with V_3^0-decay process. For events with negative α interpreted as V_3^0-decays there is no tendency towards an artificial peak near 60 MeV; it is therefore remarkable that the six events should all fit the Q-value proposed by LEIGHTON *et al.* On the other hand it is not difficult to explain the events by other processes. In Table II we show, for these six events, the errors which must be assumed in the measurements if the decays are to be interpreted as

those of Λ^0 or θ^0-particles. The figures given are reciprocal momenta as, in a first approximation, the errors in these are normally distributed. In each of the three chambers concerned the maximum detectable momentum is about $5\cdot10^9$ eV/c; this corresponds in the units used in Table II to 0.02 $(10^8\ \text{eV/c})^{-1}$.

TABLE II.

(*All reciprocal momenta are in units of* $(10^8\ \text{eV/c})^{-1}$).

Event	Measured values			Correction for Λ^0		Correction for θ^0	
	$1/p_+$	$1/p_-$	φ	$1/p_+$	$1/p_-$	$1/p_+$	$1/p_-$
1	0.53	0.48	64°	−0.39	+0.38	−0.23	−0.24
2	0.81±0.25	0.57±0.08	61°	−0.31	+0.13	+1.9	−0.44
3	0.17	0.125	14°	−0.09	+0.14	−0.09	−0.08
4	0.15	0.09	19°.5	−0.05	+0.22	−0.02	−0.03
5 (*)	—	0.15	41°	—	+0.36	—	−0.04
6	0.20±0.05	0.20±0.05	15°	−0.10	+0.09	−0.10	−0.15

Columns 5 to 8 give the corrections which must be applied to (or the errors that must be assumed in) the measured value if the event is to be interpreted as an Λ^0 or a θ^0 decay.

For a chamber with maximum detectable momentum $= 5\cdot10^9$ eV/c, the standard error in $1/p$ is 0.02 $(10^8\ \text{eV/c})^{-1}$.

(*) In event 5 the positive momentum could not be measured. The negative momentum has been adjusted to give the best fit with the observed ionization of the positive particle, from 2 to $5\cdot I/I_0$.

We see that only in two cases, events (1) and (3), is there any serious difficulty in interpreting the events as Λ^0 or θ^0-decays. The Pic-du-Midi group do not consider that event (3) is completely irreconciliable with Λ^0 or θ^0-decay; and it is now considered by LEIGHTON that event 1 could well be a charged V-decay.

Conclusions.

1) The published data as a whole is not inconsistent with the hypothesis that the only V^0-decays are those of Λ^0 and θ^0-particles.

2) Some of the anomalous events could be interpreted as τ_0-decays. But the preponderance of positive α-values makes it unlikely that in the bulk of the decays the charged secondary products had equal masses.

3) Most of the events which are least consistent with the Λ^0 or θ^0-decay processes can be interpreted as V_3^0-decays with a Q-value of about 60 MeV. The six of these events with $\alpha \leqslant 0$ are all consistent with V_3^0-decay; though

this may well be fortuitous it is not a spurious effect produced, as in the case of positive α-values, by selection bias.

* * *

I have had the benefit of several valuable discussions with Prof. AMALDI and my colleagues at the University of Rome, and also, by correspondance, with Dr. C. C. BUTLER and Mr. J. A. NEWTH.

I am very much obliged to the Government of Italy for a scholarship which has contributed to enabling me to work in Italy.

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Sur le signe de la particule K_μ.

R. ARMENTEROS, B. GREGORY, A. LAGARRIGUE, L. LEPRINCE-RINGUET, F. MULLER et CH. PEYROU

Laboratoire de Physique de l'École Polytechnique - Paris

Nous avons publié dans un article récent [1] les principaux résultats obtenus sur les particules K, à l'aide des deux chambres de Wilson du Pic-du-Midi (*).

Dans cet article, nous avons montré l'existence probable d'une particule K_μ ayant les proprietés suivantes:

1) Une vie moyenne longue car ces particules sont arrêtées dans une des plaques de la chambre du bas, après avoir vécu plus de $5 \cdot 10^{-9}$ s (traversée des deux chambres).

2) La masse moyenne de ces particules, mesurée par la méthode moment-parcours est $914 \pm 20\ m_e$. La moyenne est prise sur 8 particules, les erreurs individuelles vont de ± 40 à $\pm 80\ m_e$, ces mesures individuelles sont bien distribuées autour de la moyenne.

3) Le secondaire émis est un méson μ. En effet les parcours observés dans certains cas sont beaucoup trop grands pour un méson π, émis par une particule de masse 914.

4) La particule K_μ se décompose probablement suivant le schéma

$$K_\mu \to \mu + \nu .$$

En effet aucun arrêt du secondaire n'a été observé qui indique que l'énergie de ce secondaire est répartie suivant un spectre. Au contraire les deux arrêts

[1] *Nuovo Cimento*, **11**, 292 (1954).

(*) Les frais d'installation et de fonctionnement de cet appareil sont couverts par le Commissariat à l'Energie Atomique et l'Enseignement Supérieur.

observés donnaient pour le secondaire μ des moments de 215 ± 4 et 223 ± 4 MeV en très bon accord avec la masse mesurée et l'hypothèse de la désintégration en deux particules.

Depuis la publication de l'article nous avons observé un troisième cas d'arrêt du secondaire. Le parcours de ce secondaire est compris entre 86 et 96 g cm^{-2} de Pb, ce qui donne une mesure de moment $p = 219 \pm 4$ MeV/c. (L'erreur indiquée est une déviation standard mais il ne faut pas oublier que l'erreur principale est due à l'incertitude du point d'arrêt dans le dernier écran. Il ne s'agit donc pas d'une erreur gaussienne et il faut considerer ± 7 comme une limite quasi absolue des erreurs).

Cette nouvelle mesure confirme l'hypothèse de la désintegration en deux corps. La masse du K_μ déduite de l'énergie du secondaire est 908 ± 12 m_e.

Nous avons actuellement 11 particules du groupe K_μ. Deux particules à secondaire de parcours inférieur à 20 g cm^{-2} de Pb, qui sont probablement des τ et 6 particules qui peuvent être soit des τ, soit des K_μ.

Ces 19 particules sont toutes positives.

Nous avons donc fait une étude poussée de nos photographies (environ 20 000) pour rechercher les particules négatives correspondantes.

Une particule K négative peut:

1) Se désintégrer sans être capturée par un noyau. Dans ces cas son aspect dans la chambre à écrans ne sera pas différent d'un évènement S dû à un K^+.

2) Etre capturée par un noyau en donnant une étoile avec des branches lourdes visibles dans la chambre, ou un méson π visible dans la chambre. Dans ce dernier cas, l'aspect serait également celui d'un évènement S.

3) Etre capturée sans donner de secondaire visible. Cette dernière hypothèse est plus probable que 2), étant donné l'épaisseur des plaques.

Il est évidemment aussi probable de trouver des évènements du type 1) et 2) que des évènements S dus à des K^+.

Nous n'en avons trouvé aucun.

Les évènements du type 3) sont également faciles à reconnaitre. En effet l'arrêt d'une particule et specialement d'une particule nettement plus lourde que le méson π, a un aspect bien caracteristique dans une chambre à écrans.

Parmi les évènements de ce type, la très grande majorité étaient des protons.

Trois de ces évènements étaient des particules K positives (comptées dans les 19 citées plus haut) ayant des masses 970 ± 75, 915 ± 80, 885 ± 60 m_e; l'une d'elles avait, en fait, un secondaire peu visible et qui ne fut trouvé qu'après la mesure de masse.

Par contre nous n'avons trouvé aucune particule négative, s'arrêtant dans la chambre à écrans, et dont la masse soit comprise entre 850 et 1 050.

Une seule particule négative (différente du méson π) a été trouvée donnant un arrêt bien caractérisé. Cette photographie (26945) est representée sur la Fig. 1. On voit que en dessous du point d'arrêt une paire d'électrons est émise. Bien que la coincidence dans l'espace ne soit pas excellente, on peut penser, sans en être sur, que ceci est du à l'émission d'un γ produit dans l'évènement qui a suivi l'arrêt de la particule.

La masse trouvée pour cette particule est 1250 ± 90.

Etant donné le caractère paradoxal de l'absence de particules K négatives, nous avons fait des mesures de masse pour des évènements qui étaient très probablement des interactions de méson π, mais qui à la rigueur auraient pu être interpretés comme des arrêts par ionisation.

Nous n'avions, en fait, que deux cas de ce type. Les masses trouvées par le primaire, si l'on considère l'arrêt comme normal, sont 815 ± 65 et $1790^{+150}_{-150}\, m_e$. Ceci rend leur interpretation comme arrêts de particules K encore plus douteuse.

Nous pouvons donc résumer nos résultats de la façon suivante.

Parmi les particules ayant vécu plus de $5 \cdot 10^{-9}$ s, nous avons trouvé 19 particules K positives de masse comprise entre 850 et 1050, 4 ou 5 de ces particules étaient probablement des τ, le reste très probablement des K_μ.

Aucune particule négative, ayant vécu plus longtemps que $5 \cdot 10^{-9}$ s, n'a été trouvée dans cette intervalle de masse.

Une particule négative de masse $1250 \pm 90\, m_e$ a été trouvée.

Il ne faut pas oublier que cet évènement unique n'est pas une preuve absolue, car il pourrait être du à une interaction de π^- émettant un proton dans le prolongement du π. Cependant l'aspect de la trajectoire et l'émission possible d'un γ au point d'arrêt rendent cette interprétation peu probable.

Il est impossible d'expliquer par une fluctuation l'absence complète de particules négatives correspondant au 19 K^+. Il se peut q'une fluctuation ait exagéré l'excès positif. Mais l'existence d'un excès positif important, dans les particules K de vie moyenne longue semble très probable.

Ce résultat est à rapprocher de la rareté des étoiles de capture de K^- observées dans les émulsions photographiques [2].

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R. Armenteros, B. Gregory, A. Lagarrigue, L. Leprince-Ringuet,
F. Muller et Ch. Peyrou

Fig. 1.

Résultats sur les particules V chargées.

R. ARMENTEROS B. GREGORY, A. LAGARRIGUE, L. LEPRINCE-RINGUET
F. MULLER et CH. PEYROU

Laboratoire de Phisique de l'École Polytechnique - Paris

Les considérations qui suivent sont basées à la fois sur les résultats expérimentaux de l'équipe du Pic-du-Midi (Paris) (1) et ceux de la Jungfrau (Manchester) (2). Nous sommes très reconnaissant à J. A. NEWTH d'avoir bien voulu nous autoriser à citer ses résultats qui sont en cours de publication.

1. – Signe des évènements V et S.

Dans la communication précédente il a été montré que parmi les événements S produits par des particules ayant vécu un temps $T > 5\cdot 10^{-9}$ s il y avait un excès positif très important.

Si nous comparons ces résultats à ceux des chambres de Wilson, à champ magnétique, nous sommes amenés à grouper les évènements suivant le temps moyen de vol de ces particules. Les résultats sont rassemblés dans le Tableau I ou la première ligne correspond aux évènements observés dans les chambres de Wilson de petite taille [1].

La deuxième correspond à tous les évènements V et τ de J. et de P.

Parmi ceux-ci les évènements dont le primaire est mesurable correspondent à un groupe ayant vécu en moyenne un temps plus long et les chiffres correspondants sont indiqués dans la 3e ligne. Enfin les résultats sur les S observés dans la chambre du bas sont rassemblés dans la dernière ligne.

Or nous avons montré que ces évènements S sont explicables par deux particules: le τ et le K_μ.

(1) Les frais d'installation et de fonctionnement de cet appareil sont couverts par le Commissariat à l'Energie Atomique et l'Enseignement Supérieur.

(2) Dans la suite nous indiquerons par P. et J. les évènements de ces deux laboratoires.

Les chiffres de ce Tableau indiquent très fortement l'existence en grande abondance dans les évènements V d'une ou de plusieurs particules distinctes du K_μ et du τ.

TABLEAU I.

Expérience	Temps moyen (10^{-10} s)	n^+	n^-
V Manchester (Pic du Midi) Cal. Tech.	$\sim$ 3	36	46
V Jungfraujoch Paris (Pic-du-Midi)	$\sim$ 8	73	38
V Jungfraujoch Paris (Pic-du-Midi) (Primaire à moment mesurable)	$\sim$ 14	30	10
S Paris (Pic-du-Midi)	> 50	19	1

Cette ou ces particules doivent se présenter en totalité ou en partie sous la forme négative, et avoir une vie moyenne plus courte que celle du K_μ et du τ.

2. – Études des V chargés dont le moment dans le centre de masse est mesurable.

Pour étudier les propriétés de cette particule nous avons rassemblé les évènements V à primaire et secondaire mesurables (10 cas J.; 14 cas P.) et les τ (1 cas J.; 2 cas P.). Certains de ces évènements ont un intérêt tout particulier.

Évènement (J.) RP 993+. Les mesures de moment sont telles que l'analyse dans le centre de masse de cet évènement impose pour le primaire une masse supérieure à 1000 m_e. Or l'estimation directe de la masse excluant un hyperon nous avons donc l'évidence d'une particule K distincte du K_μ et du τ.

Évènement (P.) 35467+. Les caractéristiques de cette désintégration sont: p (primaire) $= 365 \pm 8\%$ MeV/c; I/I_0 (primaire) = 2-4; p (secondaire) = $= 206 \pm 6\%$ MeV/c; $\theta = 27°.5 \pm 0°.5$. Le secondaire s'arrête dans la chambre à écrans après un parcours de $66,4 \pm 1$ g/cm² cuivre. La masse de ce secondaire est $m = 190 \pm 21$ m_e.

Nous avons donc la désintégration d'une particule K en une particule μ: le moment dans le centre de masse de ce secondaire est, dans l'hypothèse

M primaire $= 920\ m_e$

$$p^* = 108 \pm 6 \text{ MeV/c} .$$

Cette particule n'est donc ni un τ ni un K_μ.

Nous avons complété ces informations en groupant dans le Tableau II tous les évènements J. et P. où le p^* est calculé en supposant une masse 920 m_e pour le primaire et une nature μ pour le secondaire.

TABLEAU II.

Signe \ p^* (MeV/c)	$\ll 220$	< 220	$= 220$	> 220	$\gg 220$	τ
+	9	1	5	0	1	3
—	3	2	2	1	0	0

Les différentes colonnes correspondent aux évènements pour lesquels le p^* diffère de plus de deux écarts quadratiques moyens ($\ll$ ou $\gg$) ou de un écart quadratique ($<$ ou $>$) de la valeur 220 MeV/c qui correspond à la ligne du K_μ.

Nous remarquons que les douze évènements de la première colonne ne peuvent être des K_μ à cause de la faible valeur de p^*. De plus si nous considerons que seulement 3 τ ($\pi^+ + \pi^- + \pi^+$) ont été observés dans les mêmes conditions, il est difficile d'admettre que tous ces évènements représentent un mode alterné de mort du $\tau \to \pi^\pm + 2\pi^0$. Comme de plus l'évènement 35467 indique la présence de μ parmi les secondaires des évènements de ce type, il est nécessaire d'admettre que la majorité de ces évènements ne correspondent pas à la desintégration $\tau \to \pi + 2\pi^0$.

L'évènement de l'avant dernière colonne est le RP993 (J.), qui, nous l'avons vu, ne peut correspondre à une particule K_μ.

Les évènements de deux autres colonnes peuvent s'interpreter en partie comme des évènements K_μ (*).

Cependant l'abondance des particules négatives dans ce groupe indique la présence d'une particule distincte.

En résumé, l'étude des V dont le moment dans le centre de masse est mesurable, impose l'existence d'au moins une particule distincte du τ et du K_μ.

Si cette particule est unique, elle doit avoir: une masse supérieure à 1000 m_e, une désintégration en plus de deux corps le secondaire chargé étant un méson μ, et un signe positif et négatif. Enfin sa vie moyenne doit être inférieure à celle de la particule K_μ.

Nous l'appelerons $\varkappa^\pm$ car elle présente des caractères identiques à la parti-

(*) Deux évènements positifs donnant des excellentes determinations du p^* compatibles avec 220 MeV/c ont été récemment obtenues par THOMPSON (*Proc. Rochester Conf.*, 1954).

cule observée dans les émulsions photographiques. Nous voyons qu'elle peut être considérée comme responsable de la majeur partie des évènements V observés à la chambre de Wilson.

3. – Nature des secondaires des évènements $V^{\pm}$.

Nous avions déjà montré [2] que lorsque le secondaire d'un évènement V traversait la chambre à écrans nous pouvions dans certain cas identifier la nature π ou μ de ce secondaire.

Nous avons observé quatre nouveaux cas appartenant à ce groupe:

Évènement 35467 décrit au § 2. Le secondaire est un méson μ.

L'évènement 27139 apparait dans la chambre du haut comme une désintégration d'un V^- suivie de la désintegration d'un V^0. L'analyse complète de cet évènement sera publiée ultérieurement. Le secondaire du V^- réagit dans la chambre du bas ce qui prouve sa nature π.

Or il est fort probable [3] que le V^0 associé à ces évènements est un Λ^0. Si ceci est exact notre évènement prouve la nature π du secondaire de la désintégration de cet hypéron.

Évènement 35354 V^-. p secondaire $\cong 2$ GeV/c; $\theta \sim 5°$. Ce secondaire réagit dans la chambre à écrans, c'est donc un méson π^-.

Évènement 33284 V^+. Le secondaire traverse 0,8 λc avant de sortir de la zone éclairée.

Si l'on cherche à introduire le nombre minimum de particules nouvelles nous voyons que parmi les V chargés il existe une autre particule dont le secondaire est un π et qui est fort probablement un hypéron.

Cette particule n'a jusqu'à présent été observée que sous forme négative.

4. – Vie moyenne.

Malgré le faible nombre d'évènements observés dans la chambre du haut, et l'imprécision que nous avons encore sur les proportions relatives des différentes particules, il se trouve que la comparaison directe du nombre de V observés dans la chambre du haut et du nombre d'S observés dans la chambre du bas permet de calculer la vie moyenne de ces particules avec une bonne approximation.

Il est nécessaire de définir dans la chambre du haut une région de bonne observation des évènements V. Nous avons choisi une région autorisant une bonne mesure du primaire pour une valeur de celui-ci d'environ 500 MeV/c.

Dans cette région nous devons compter le nombre d'évènements dont les

primaires, s'ils n'avaient pas subi de désintégration, seraient venus s'arrêter dans la chambre du bas. Nous avons trouvé dans une région correspondant à une vie de

$$10^{-9} < T < 1{,}6 \cdot 10^{-9}\ \mathrm{s}$$

14 particules dont 5 se dirigeaient vers la chambre du bas et 5 avaient un primaire dont le moment avait la bonne valeur. Le nombre de particules K, ayant à la fois ces deux propriétés et se désintégrant dans un temps de $0{,}6 \cdot 10^{-9}$ s, était donc de

$$\frac{5}{14} \cdot \frac{5}{14} \cdot 14 = 1{,}8 .$$

Or nous avons vu que parmi ces particules il y avait une majorité de $\varkappa^{\pm}$ et un nombre faible de K_{μ} et de τ.

Au cours de la même expérience nous avons observé 11 K_{μ}^{+} dans la chambre du bas, 5 particules qui s'interprètent au mieux comme des τ^{+} et une particule négative de masse 1250 qui peut s'interpreter comme un $\varkappa^{-}$. Toutes ces particules ont vécu plus de $5 \cdot 10^{-9}$ s.

Nous pouvons donc en déduire:

a) Il est encore impossible de distinguer entre les vies moyennes du τ et du K_{μ}. Si, d'après les résultats du § **2**, nous estimons à 15% la proportion de K_{μ} dans la chambre du haut (dans la bande de moment considérée) la vie moyenne du K_{μ} est de $2{,}8 \cdot 10^{-8}$ s.

Il faudrait augmenter le nombre de K_{μ} dans la chambre du haut d'un facteur 5 pour que cette vie moyenne descende en dessous de 10^{-8} s.

b) Nous pouvons donner une limite supérieure à la vie moyenne $\tau_{\varkappa}$ du $\varkappa$ en considérant que le nombre de $\varkappa$ observés dans la chambre du bas était inférieur à 4, et le nombre correspondant dans la chambre du haut superieur à 1. Ceci donne:

$$\tau_{\varkappa} < 5 \cdot 10^{-9}\ \mathrm{s}\ .$$

La meilleure estimation serait:

$$\tau_{\varkappa} \sim 2{,}4 \cdot 10^{-9}\ \mathrm{s}\ .$$

c) En prenant ces deux meilleurs estimations, nous pouvons en déduire le rapport à la production du K_{μ}^{+} et du $\varkappa^{\pm}$, ce rapport est: $K_{\mu}^{+}/\varkappa^{\pm} \sim 1.7$.

Il est important de remarquer que les chiffres indiqués dans ce § **4** ne doivent être considérés que comme des ordres de grandeur raisonnables.

La justification d'une telle étude est qu'elle permet de comparer nos ré-

sultats avec ceux d'observateurs travaillant avec des émulsions photographiques ou des chambres à écrans.

Pour les émulsions, toutes les particules τ, K_μ et $\varkappa^\pm$ seront arrêtées. L'on devrait donc observer parmi les évènements K une proportion $K_\mu^+/\varkappa^+ = 3{,}5$ et un nombre de $\varkappa^-$ sensiblement égal à celui des $\varkappa^+$.

Pour les chambres à écrans le temps moyen d'arrêt d'une particule crée dans un écran est de 10^{-9} s, l'on doit donc observer un certain nombre d'évènements V dus à la desintégration en vol d'une particule $\varkappa^\pm$ ($\sim 15\%$), un certain nombre d'évènements S dus à la particule K_μ^+ ($\sim 70\%$) et un certain nombre d'évènements S dus à la particule $\varkappa^+$ ($\sim 15\%$).

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Report on a Negative Heavy Meson Observed at the Pic-du-Midi.

N. C. BARFORD
Imperial College of Science and Technology - London

Some two years ago the following event was observed by BARKER in the 30 cm diameter cloud chamber working at the Pic-du-Midi.

Although it is by no means certain, it probably represents the capture of a negative heavy meson. It may therefore be of interest to recall this, in view of the fact that the group of the École Polytechnique, Paris, find such a predominance of positive heavy mesons stopping in their multiplate chamber. The latest information I have is that 12 $K^{\pm}$ and 6 τ^{+} have been found, but this may well be modified by now.

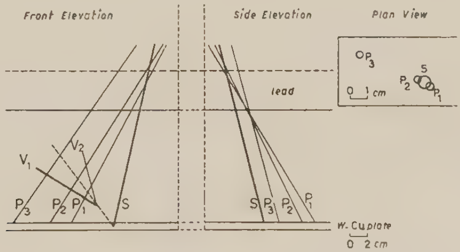

Fig. 1. – Spatial relationships for the S-particle event.

The event is shown in Fig. 1.

On the left is a Λ^0 and the plane of this is intersected by the nearly vertical track near the bottom of the plate. The latter could be interpreted as:

a) an upward moving positive particle;

or

b) a downward moving negative particle, captured in the plate and giving rise to a Λ^0.

Momentum-ionization ($I/I_0 = 3\text{-}6$) measurements give the mass to be in

the region 1100-2000 m_e and for *b*) we may also use a range-momentum estimate of the mass, which is 1800^{+900}_{-400} m_e.

Further, the near concurrence of the track and the two shower particles P_1 and P_2 makes *a*) very improbable. We therefore are left with the most likely interpretation, that the event is a K^- capture, although it might possibly be a τ^- capture. It is consistent with the scheme:

$$K^- + p \to \Lambda^0 + \pi^0 ,$$

which would require $m_{K^-} \sim 1000$ m_e.

As the interaction takes place near the bottom of the plate we should not expect the π^0 to give observable products.

This type of interaction might well explain the K-mesons stopping without visible products, such as those described by VON FRIESEN at this Conference (*).

(*) See in this issue, pag. 273.

Report on the High Pressure Cloud Chamber at the Marmolada.

G. R. EVANS
University of Edinburgh - Edinburgh

Members of the group:

a) From University College, London,
P. BAXTER, E. H. S. BURHOP, H. S. W. MASSEY, A. J. METHERINGHAM, N. MORRIS, P. PROBST, R. STONNARD, H. S. TOMLINSON.

b) From the University of Edinburgh,
G. R. EVANS, E. J. WILLIAMS.

Since July 1953, we have been operating a high-pressure Wilson cloud chamber at the mountain station on the Marmolada at an altitude of 6 600 ft. This experiment has been made possible by the kind generosity of Professor ROSTAGNI of the University of Padua, who has provided us with the accommodation at this station.

The many interesting events that have so far been obtained have been encouraging enough to warrant the construction of a new chamber of diameter 32 cm to be used in conjunction with a field of 10 000 oersted. The present chamber, which was designed by the late E. J. WILLIAMS, had been operating successfully since 1939 at Aberystwyth, in Wales: in the present investigations it has been used with Argon at 80 atmospheres pressure. To date 2 000 photographs have been taken, mostly of high quality. These photographs have not yet been examined in detail; it was decided that in the first instance it would be more profitable to make a thorough examination of a few selected events, the nature of which could be in no doubt. For example, of twelve examples of V^0-decay which have been observed, three could be said to represent the decay of the Λ^0. The analysis of these events should therefore yield a Q-value near 37 MeV. The results of these measurements, which are given in Table I, show satisfactory agreement with the accepted Q-value. One of these Λ^0 decays (event No. 608) is shown in Fig. 1.

The importance of using high pressures is shown by the fact that in the case of one of the V^0-decays (believed to be a θ^0-decay) the parent star is also

TABLE I.

Event No.	$p\beta$(MeV/c)	$p\beta$(MeV/c)	Decay	Q(MeV)
	(a)	(b)		
412	136	110	$\Lambda^0 \to p + \pi$	48
608	90	120	»	35^{+17}_{-8}
1 527	75	94	»	30

formed in the gas: the star has only 6 prongs of low energy, but it is possible that one of these may represent the track of a light meson.

For the analysis of these photographs, the following measurements can be made:

1) multiple scattering measurements, giving $p\beta$;

2) the number of δ-rays per unit length;

3) the energy and direction of projection of knock-on electrons;

4) track width;

5) residual range (when the particle is stopped in the chamber).

The velocity of the particle can be estimated by using 2), 3) and 4), and this together with 1) or 5) enables a measurement of its mass to be made. Several thousand ion-pairs are produced along each centimeter of track in the chamber, and therefore it seemed to us that it should be possible to obtain valuable information even from short tracks, of length, say, not greater than 1 cm. Hence it was decided to explore the possibility of obtaining this information from the track width. This problem presents many difficulties: the track width as seen on the negative, can be affected in a variety of ways, the most important of which are due to 1) uneven illumination, 2) changing expansion ratio, 3) variation of the time in which the drops are allowed to diffuse, 4) the distance of the track from the camera (the magnification will depend upon this distance and also the track may be out of focus). In view of these difficulties, it was decided to confine our measurements to tracks on one photograph which were in good focus and in the central region of the chamber. Further, to avoid any complications due to changes of magnification, it was decided to use the reprojection method for the measurement of the track widths.

Fortunately, a star having 23 prongs (Fig. 2) was found to satisfy these criteria, and in addition showed tracks of two protons a) and b), and one α-particle c) which stopped in the chamber. Fig. 3 shows the results of these measurements compared with the calculated value of the ratio $(I/I_{\min})$, where I is the ionisation loss per cm of track and $I_{\min}$ is its minimum value. This shows

Fig. 1.

Fig. 2. The data for Fig. 3 was obtained from this star

that it is possible by this method to determine the direction of flight of low energy protons and α-particles. This figure was used to determine the ratio (I/I_{min}) for the track of the incident particle d), which gave a value of 1.38.

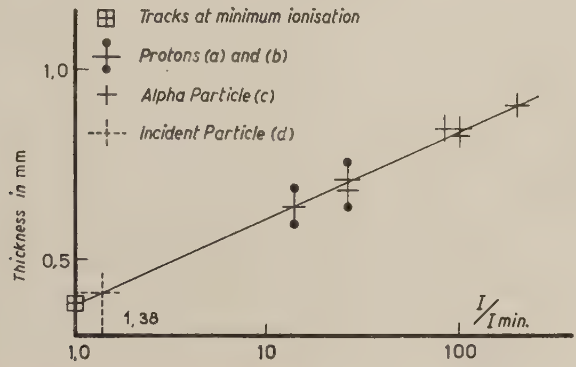

Fig. 3.

This figure agrees very closely with that to be expected for a very energetic particle of unit charge. These measurements are being extended to cover less favourable cases.

* * *

In conclusion, we should like to thank Prof. A. LORIA and his group who have made our task of assembling the chamber at the Marmolada so much easier.

Getti e sciami penetranti.

Sulla distribuzione angolare nei getti.

G. BERTOLINO, D. PESCETTI e L. TALLONE

Istituto di Fisica dell'Università - Torino
Istituto Nazionale di Fisica Nucleare - Sezione di Torino

Sono in corso misure su un gruppo di getti osservati nelle lastre che hanno volato a Cagliari nel 1952 e nel 1953, in parte con primario neutro ed in parte con primario carico. Si è riscontrata dalle prime misure una concordanza assai soddisfacente coi diagrammi illustrati da DULLER e WALKER [1], dai quali risulta una relazione rettilinea con pendenza 2 fra il logaritmo della $\operatorname{tg}\vartheta$ ed il logaritmo del rapporto $f/(1-f)$. Per comprendere i vari getti in un unico diagramma, si è riportato il $\log(f/(1-f))$ in funzione di $\log(\operatorname{tg}\vartheta/\operatorname{tg}\vartheta_{\frac{1}{2}})$ dove $\vartheta_{\frac{1}{2}}$ è l'angolo mediano dello sciame (Fig. 1).

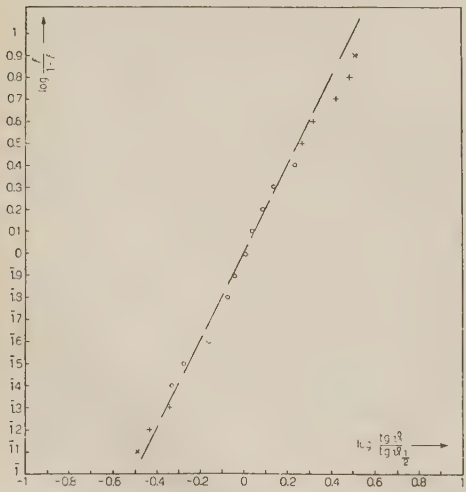

Fig. 1.

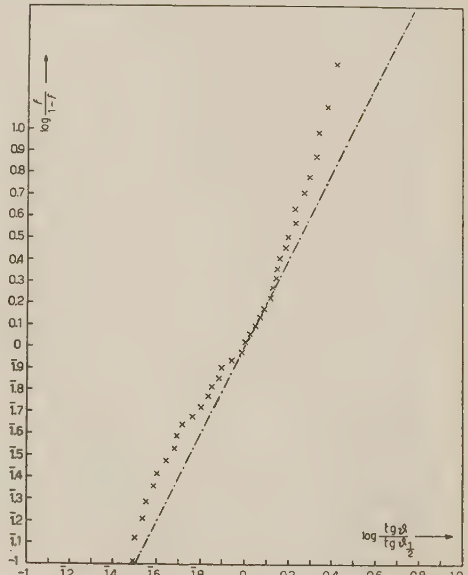

Fig. 2.

Da un punto di vista teorico questa relazione si giustifica coll'ipotesi che si tratti di un'emissione isotropa nel sistema baricentrico e che il rapporto fra la velocità del baricentro e la velocità delle particelle secondarie emesse sia praticamente uguale ad uno. Inoltre, il fatto che i dati dei vari getti si raccolgano in uno stesso diagramma è basato sulla circostanza che $\operatorname{tg} \vartheta_{\frac{1}{2}} \sim 1/\gamma_c$.

I diagrammi dati da DULLER e WALKER valgono per getti con un numero limitato di particelle: si è riscontrato (Fig. 2) che la stessa relazione si può applicare soddisfacentemente ad un getto di alta energia formato da oltre 40 particelle relativistiche (con un primario carico $Z > 1$).

Ulteriori misure sono in corso per verificare se la relazione vale ancora considerando separatamente getti con primario carico e getti con primario neutro (analogamente a quanto è stato fatto da CASTAGNOLI, CORTINI, MANFREDINI, FRANZINETTI, MORENO [2] e per studiare quali sono le eventuali modificazioni che la relazione subisce nel caso di getti con uno o più rami neri.

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Sciami penetranti in H e C.

P. Colombino, S. Ferroni e G. Wataghin
Istituto di Fisica dell'Università - Torino

Si riportano i risultati di una nuova serie di misure su sciami penetranti generati negli strati di paraffina (14 g/cm²) e di grafite (12 g/cm²), effettuate alla quota di 3 500 m (pressione atmosferica media 495 mm Hg). In aggiunta alle apparecchiature già descritte [1] si è usato un doppio odoscopio che registra tanto le particelle incidenti quanto quelle emergenti dall'assorbitore.

I risultati ottenuti mediante un'analisi degli eventi prodotti da particelle cariche incidenti e da particelle neutre hanno portato al rilevamento di un differente valore per le sezioni d'urto neutrone/protone e protone/protone. Tali dati sono raccolti nella seguente Tabella I già illustrata nella lettera al Direttore del *Nuovo Cimento*, **11**, 572 (1954).

Tabella I.

Sciami	Paraffina (P)		Grafite (G)		Fondo (O)	$P-O$	$G-O$	$P-G$
	N	frequenza	N	frequenza	frequenza	frequenza	frequenza	frequenza
DS	686	0,51 ±0,020	712	0,51 ±0,02	0,53±0,03	—	—	—
MS(p)	638	0,461±0,018	609	0,441±0,018	0,19±0,015	0,27	0,25	0,02
MS(n)	889	0,64 ±0,022	670	0,48 ±0,019	0,19±0,015	0,45	0,29	0,16

A completamento di questo lavoro diamo i valori indicativi dell'effetto barometrico calcolato mediante le usuali formule statistiche [2]; tale effetto è dell'ordine di 17% per cm Hg per gli sciami denominati « sciami densi »

(DS), ed è il 7% per cm Hg per la componente protonica e neutronica che genera sciami di moltiplicazione classificati come MS(p) e MS(n) nell'assorbitore.

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A Statistical Analysis of Jets.

T. F. HOANG

Laboratoire de Physique de l'École Polytechnique - Paris

We have analysed five n-jets and 49 p-jets with $N_h \leqslant 4$ and $N_s \geqslant 5$. These jets have been systematically selected in a general scanning of emulsions exposed at 30 km.

Assuming a single act of nucleon-nucleon collision, we have estimated the primary energy, γ', in the center of mass system (in units of Mc²) by the angular distribution of shower particles. We define for each jet a coefficient of inelasticity of collision, k, by the ratio of the mean energy of the meson in the center of mass system, to the available energy released by the two nucleons on colliding

$$k = \frac{1.5 N_{\pm} \gamma' \sin \theta_L}{2r(\gamma' - 1)},$$

where $1.5\,N_{\pm}$ is the total number of mesons ($N_{\pm} = N_s - 1$), θ_L is the limiting angle of the jet in the laboratory system and $r = 6.7$ is the ratio of mass of the nucleon to that of the π-meson.

For five cases with wide median angles ($> 20^{\circ}$), k is found to be much greater than unity. This means that some of these jets are most probably produced in more than one act of collision.

For the remaining 49 cases, we notice that it is possible to divide them into two classes according to the values of k. There are 27 jets having their values of k lying between 0.8 and 1.2, the average value being 1.05 and the root mean square value of deviation, 0.27. The k-values of the other 22 jets are statistically less than unity; their average is 0.41 with a root mean square deviation of 0.45.

If, in the latter 22 cases, we attribute some of the shower particles to mesons heavier than the π and use the theoretical results of HABER-SCHAIM for the ratio of K-mesons to π-mesons for different primary energy, we have to multiply the previously defined coefficient of inelasticity, k, by a factor of

about 2. However, the mean value of k thus obtained is still much less than unity.

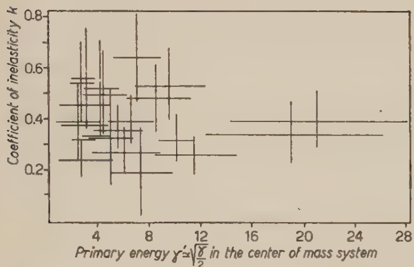

Fig. 1. – Values of k for jets of multiplicity: $N_{\pm} = 1.87\ \gamma^{\frac{1}{4}}$.

The characteristic feature of these jets with $k < 1$ is that the multiplicity is very small and increases very slowly with the primary energy. Actually, it seems that the multiplicity increases only as the fourth root of the primary energy γ, in the laboratory system:

$$N_{\pm} = (1.87 \pm 0.35)\,\gamma^{\frac{1}{4}}\,.$$

This relation is in good accord with Fermi's theory (Fig. 1).

For the jets with k equal statistically to unity, we tentatively assume that all the mesons are π's and that they are produced in a completely inelastic collision. In other words, the multiplicity in this case turns out to be proportional to the primary energy γ' in the center of mass system:

$$N_{\pm} = (3.05 \pm 0.15) - (2.33 \pm 3.14).$$

This gives for the average kinetic energy of mesons in the center of mass system, a value about twice that of the rest mass (Fig. 2).

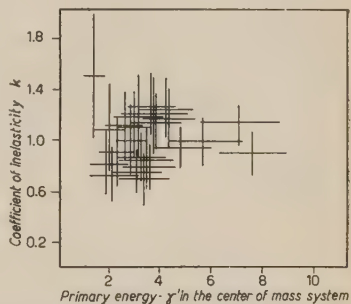

Fig. 2. – Values of k for jets of multiplicity: $N_{\pm} = 3.05\,\gamma' - 2.33$.

We have followed all the shower particles of 54 jets and have found 4 interactions for 92 cm of track length. This gives an interaction mean free path for shower particles of $\sim 23^{+20}_{-10}$ cm. The errors are fiducial fluctuations.

A full account of this work has been submitted to the *Journal de Physique*.

Remarks on the Interpretation of Jets.

U. HABER-SCHAIM

Phisikalisches Institut der Universität - Bern.

I would like to outline two points which unfortunately do not seem to simplify the interpretation of jets but may permit to widen the concept of a jet and thus improve our statistics on the subject. At this moment we have only the most preliminary experimental evidence to support our arguments and I present them here mainly to invite criticism and discussion.

It is well known that the angle, $\theta_{\frac{1}{2}}$, which contains half the particles of a jet gives us the velocity of the center of mass system relative to the laboratory system:

$$\gamma = \cot \theta_{\frac{1}{2}} \qquad \beta = \frac{\sqrt{\gamma^2 - 1}}{\gamma} .$$

This simple relation holds only if the ratio of velocities of the shower particles in the center of mass system to that of the center of mass system itself is very close to one. This seems a fairly safe assumption at least at high energies. A second assumption is that all particles of the jet are created in a single collision. A cascade process inside the nucleus would undoubtedly tend to increase the value of $\theta_{\frac{1}{2}}$. Let us limit ourselves to the case where all shower particles are created in a single collision. Here we can infer the energy of the primary particle from $\theta_{\frac{1}{2}}$ if we make definite assumptions as to the number of nucleons which take part in the collision. One usually assumes that only the incoming particle (the mass of which is unimportant at high energies) and one nucleon take part in this collision. In this case the primary energy is $E_1 = 2\gamma^2$ and the total energy in the center of mass system is $W_1 = 2\gamma$ (all the energies in units of Mc^2).

If on the other hand the incoming particle collides simultaneously with n nucleons the same angle will give a primary energy $E_n = n \cdot E_1$ and $W_n = n \cdot W_1$. Inverting this statement we may say that particles of given energy will create jets of various half angles according to the number of nucleons they hit in the collision. In order to be able to determine n one has

to know both $\theta_{\frac{1}{2}}$ and E which is seldom the case. That this types of collision may actually exist is made plausible by the following considerations. 1) Nuclear matter is very dense. 2) The range of nuclear forces is of the same order as the internuclear distances. 3) The nuclear forces are strong. Hence from a very primitive geometrical point of view, there should be a rather large probability of hitting simultaneously 2-4 nucleons. Looking at it from the point of view of perturbation theory knocking out two nucleons would be a reaction of one order higher than knocking one, but since the forces are strong, the higher order reaction may have a similar probability as the lower one. It is difficult to make quantitative statements on the relative frequency of these types of collisions, without introducing very specific assumptions. Therefore I shall only indicate some of their observable consequences.

1) Since the energy available for meson-production in the center of mass system is proportional to n, the observed multiplicity will be larger than in nucleon-nucleon collision. In Fermi's theory [1] the multiplicity will be increased by a factor $n^{\frac{1}{4}}$. The angular distribution, at least for $n = 2$ will remain unchanged (for $n = 3$ or 4 one can hardly conceive a collision with large angular momentum). It seems that stars where the angular distribution fitted the Fermi theory but the multiplicity was too low, were actually observed [2].

2) The apparent small inelasticity of nuclear collisions and the rather large ratio of neutral to charged stars producing particles may also be due, at least partially, to the many nucleon collision.

In conclusion I wish to stress that this model is not intended as a substitute for the nuclear cascade inside the nucleus but is meant to indicate that a cascade of two-body collisions may not be sufficient to give a full explanation of the observed stars, in particular of those produced in light nuclei.

Now to the second point. It is customary to classify cosmic ray stars according to the number of shower particles N_s and slow particles $N_h \leqslant 2$ are usually interpreted as « glancing collisions » i.e. a nucleon-nucleon collision occurring at the edge of the nucleus. Stars with $N_h \geqslant 3$ are taken to be due to a more complicated collision. I would like to suggest that by making this limitation we throw away a rather large number of stars where the jet part i.e. the narrow cone is essentially due to such a glancing collision. But a large number of heavy tracks are due to a secondary interaction of a low energy particle. The probability of such an event is dependent upon the particular theory used to describe the nucleon-nucleon collision. As an example we may consider a glancing collision of a nucleon of $E = 100$ GeV with a nucleus of atomic weight $A = 100$. Then for a median impact parameter the Fermi theory will predict that on the average 1.3 particles of energy of a few GeV will traverse at least one mean free path of nucleon matter inside the nucleus. For smaller impact parameters this number will increase. If one of these

particles makes a secondary collision inside the nucleus the star will look like a superposition of a nucleon-nucleon collision of energy $E_1 \sim 100$ GeV and a star produced by a primary of $E_2 \sim 5$ GeV. This superposition will hardly affect the cone of the shower particles but will add a considerable number of grey and black tracks. Unfortunately it is impossible to say by looking at an individual star if it is a glancing collision as described here or a central collision involving a cascade. But if we had a considerable number of stars it may be possible to distinguish between this two cases by plotting the angular distribution of the shower particles in the center of mass system as determined by the $\theta_{\frac{1}{2}}$ method.

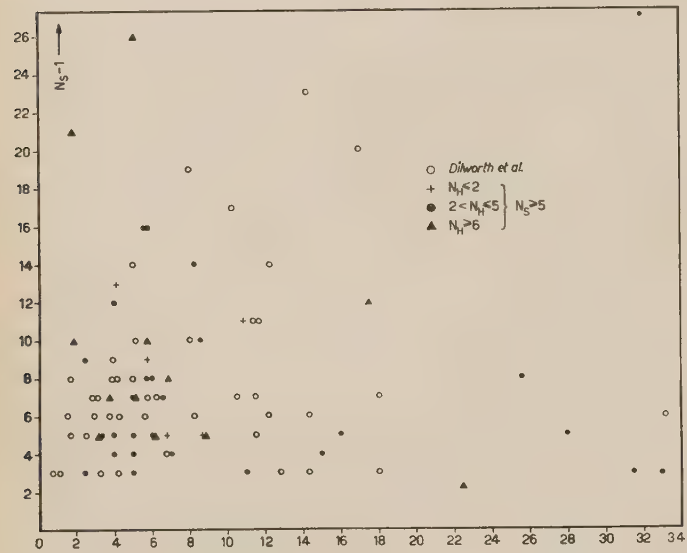

Fig. 1.

This is presently done in Berne, but our statistics is still limited. Preliminary results obtained by A. ENGLER seem to indicate that stars with $N_h \geqslant 3$ are distributed in a similar way in a N_s versus γ diagram as those with $N_h \leqslant 2$. A comparison with the results of DILWORTH *et al.* [3] is given in Fig. 1.

* * *

It is a pleasure to thank Prof. F. G. HOUTERMANS for his interest and encouragement, Dr. A. ENGLER for making his results available prior to publication and Dr. M. TEUCHER for helpful discussions.

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On the Composition and Properties of Shower Particles Produced in High Energy Interactions.

D. LAL, YASH PAL and RAMA

Tata Institute of Fundamental Research - Bombay

Seventy-nine high energy interactions ($E = 50 \div 1\,000$ GeV/nucleon) were studied for determining the composition and properties of shower particles. Investigations were carried on along two lines:

1) Determination of production frequency of neutral π-mesons by making observations on electron-positron pairs found in shower-cores.
2) Search for interactions produced by shower particles by tracing the shower tracks through the emulsion.

The showers were discovered in a stripped emulsion block [1] which was flown for several hours above 75 000 feet at geomagnetic latitude 19° N.

1. – Production Frequency of Neutral π-Mesons.

The primary energy of the interactions was determined from the median angle of showers particles. The energies of 15 showers selected for this investigation lay between 50 and 250 GeV/nucleon, the median energy being 100 GeV/nucleon (multiplicity $N_s = 8 \div 155$).

A search was made under high resolution for pairs formed within 6 mm from the origin of the interaction. The number and the track lengths of the charged particles falling in the surveyed area were determined from accurate plots and angular distributions.

In order to keep the detection efficiency as high as possible the following restrictions were imposed:

a) We do not consider any pairs formed up to 100 μ from the shower origin since the track density is very large.

b) We do not consider any pairs formed within 40 μ depth from the exit surface of the emulsion since for such pairs the projected length of the pair becomes small and the detection efficiency decreases. With this restriction only pairs whose projected length exceeded 120 μ were included.

Evaluation of the ratio. – For the evaluation of the ratio it is assumed that:

a) the pairs have been detected with 100% efficiency;
b) the angular distribution of neutral π-mesons is identical with those of charged particles;
c) the pairs observed are due to γ-rays arising from the decay of neutral π-mesons only.

Other possible known sources of γ-rays are:

1) Direct production in nuclear collisions due to « Bremsstrahlung » of nucleons and mesons. OEHME's [2] calculations show that at energies of the order of 100 GeV these corrections are very small for mesons of spin zero.
2) Cascade multiplication (*). This effect should be relatively small up to a distance of 6 mm (0.16 conversion units). In order to see if any significant effect does exist, the distance from the shower origin in which pairs were observed was subdivided into three regions extending to 0.08, 0.12 and 0.16 conversion units respectively. These separate results are given in Table I.

TABLE I.

Distance from shower origin	Total track lenght due to showers particles	No. of pairs	N_{π^0}/N_s
Up to 3 mm	93.9 cm	20	0.40 ± 0.09
Up to 4.5 »	107.8 »	23	0.40 ± 0.08
Up to 6 »	128.2 »	32	0.47 ± 0.08

(*) In a previous paper from this laboratory by LAL *et al.* [4] the ratio N_{π^0}/N ch. meson was determined as 0.86 ± 0.1 in a shower of 210 charged particles produced by a Magnesium nucleus ($E = 7.8 \cdot 10^{12}$ eV/nucleon). Here the measurements were carried out up to a distance of ~ 0.7 conversion units and the results corrected for cascade multiplication. However, this correction in the beginning of a cascade development is subject to considerable uncertainty and we, therefore, consider the previously published value to be unreliable.

Since we do not take into account any pairs formed up to 100 μ from the origin the corrections due to:

i) the finite path length travelled by π^0-mesons before decay ($\tau = 5\cdot10^{-15}$ s);

and

ii) the direct conversion of π^0 according to the alternative mode of decay [3],

$$\pi^0 \rightarrow 2e + \gamma$$

are very small.

A total of 32 pairs was found corresponding to 555 charged shower particles with an aggregate path length of 128.2 cm.

This gives $N_{\pi^0}/N_s = (32\cdot 3.75)/(2\cdot 128.2) = 0.47 \pm 0.08$, considering pairs formed up to 6 mm from shower origin. (A conversion unit in emulsion for high energy photons is taken to be 3.75 cm).

Within the statistical accuracies given in Table I, the three ratios agree. Cascade effects are, therefore, believed to be less than 20% up to the largest distance surveyed (0.16 conversion units), and negligible at 0.12 conversion units. We take, therefore, as the best value in this energy region,

$$N_{\pi^0}/N_s = 0.40 \pm 0.08.$$

Our results and those of other workers are listed in Table II.

TABLE II.

Primary energy (GeV/nucleon)	Ratio N_{π^0}/N_s	Reference
50-3 000	0.33 ± 0.07	DANIEL *et al.* [5] . . . . . .
20 000	0.25 ± 0.1	MULVEY [6] . . . .
50 000	0.44 ± 0.14	NAUGLE and FREIER [7] . . .
$\geqslant$ 1 000	0.46 ± 0.09	KAPLON *et al.* [8] . . . .
50-250	0.40 ± 0.08	Present work . . . .

The weighted mean of all these results is 0.40 ± 0.04 and lies within one standard deviation from all values except MULVEY's, from which it is within $1\frac{1}{2}$ standard deviations. If the ratio N_{π^0}/N_s varies with energy in the energy region from 100 GeV to 50 000 GeV, this variation is at present obscured by statistical uncertainties.

The number of protons in high energy interactions has been determined as 10% of the shower particles by DANIEL *et al.* [5]. Thus, using the mean of the values obtained from Table II, one obtains:

$$\frac{N_{\pi^0}}{N_{\pi^\pm} + N_{K^\pm} + N_{Y^\pm}} = 0.44 \pm 0.04 \,.$$

where $K^\pm$ and $Y^\pm$ stand for K-mesons and hyperons respectively. If we assume that the ratio $N_{\pi^0}/N_{\pi^\pm}$ is always equal to 0.5, as it is at low energies [5, 9, 10] we than obtain an upper limit on the production frequency of K-mesons and hyperons:

$$\frac{N_{K^\pm} + N_{Y^\pm}}{N_{\pi^\pm}} \leqslant 0.25$$

and

$$\frac{N_{K^\pm} + N_{Y^\pm}}{N_s} \leqslant 0.18 \,.$$

As pointed out earlier this limit is underestimated if there is some other mechanism for producing high energy γ-rays near the point of interaction.

2. – Interaction Properties of Shower Particles.

The showers used for this investigation were produced by primaries with energies lying between 50 and 1000 GeV per nucleon and the number of charged shower particles in each shower varies between 5 and 40 per incident nucleon.

In all, 1635 shower tracks were examined for a total track length of 439 cm in emulsion and 15 secondary interactions were observed, corresponding to an interaction mean free path of 29.3 ± 7.6 cm. Types of secondary interactions looked for included:

i) stars;

ii) charge exchange scattering (no case was observed);

iii) ordinary scattering through an angle greater than 10° (one case was observed).

The data on secondary interactions in similar investigations reported previously from this laboratory and Bristol is given in Table III.

Combining all the results, we get an interaction mean free path of

TABLE III.

Primary energy (GeV/nucleon)	Track length (cm)	No. of interactions	Reference
8000	201	8	LAL *et al.* [4]
50÷3000	129	5	DANIEL *et al.* [5]
20000	140	4	MULVEY [6]
50÷1000	439	15	Present work
Total . .	909	32	

28.4 ± 5.0 cm for shower particles in emulsion, while the value of interaction mean free-path corresponding to geometrical interaction cross-section in G-5 emulsion is 27 cm. (This value is based on a nuclear radius of $1.38 \cdot 10^{-13} A^{\frac{1}{3}}$ cm for each constituent nucleus of atomic weight A). The result indicates that probably all shower particles interact with nearly geometric cross-section. However within statistical accuracy the result allows still a small admixture (less than 19% of non-interacting shower particles).

It has been observed that in the secondary stars produced by shower particles the number of heavy prongs, N_h, is generally very small. The distribution of secondary stars with respect to N_h is given in Table IV.

TABLE IV.

N_h	0	1	2	3	4	5	6	7	8	9	10	11	12	13
No. of secondary stars	1	8	—	1	—	—	2	—	—	1	1	—	1	—

The number of charged shower particles, N_s, in these interactions varies from 0 to 4. In the secondary interactions with N_s varying from 1 to 4, we find the average N_h to be < 4. In stars having similar number of charged particles but produced by all cosmic ray components (presumably mostly nucleons), CAMERINI *et al.* [11] find the average N_h to be about 10. In both cases the energies of the particles responsible for the interaction lie in about the same energy interval. There is then some indication that meson production by particles emerging from energetic showers causes less excitation in the target nucleus than meson production by nucleons. A similar indication was obtained in an earlier publication from this laboratory [4].

We observed only two deflections of $\sim 5^o$ each in all the 1635 shower tracks. These two particular tracks before the deflection could be identified as due to π-mesons. One case could be interpreted as due to $\pi \to \mu$ decay or due to scattering; the second case as that of scattering only.

We observed no event which could be interpreted as the decay of K-meson into L-meson.

Two events were observed in which the shower particle gives rise to only one grey proton track. If they are assumed to be the decays of a charged hyperon into proton and a neutral pion, the Q-values turn out very large (0.4 and 1.4 GeV, respectively). It seems very unlikely that either of these events is caused by hyperon decay.

* * *

We are deeply indebted to Prof. B. PETERS for continuous discussions, and keen interest in this work. We very much appreciate the co-operation given to us by Dr. R. R. DANIEL, G. FRIEDMANN and Miss P. A. IRANI.

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SUPPLEMENTO AL VOLUME XII, SERIE IX DEL NUOVO CIMENTO N. 2, 1954

Nuclear Disintegration Cascade Produced by a Heavy Primary.

A. MILONE

Istituto di Fisica dell'Università - Genova

An event, found a few days before this conference started, is shown, consisting of a succession of nuclear disintegrations initiated by a heavy primary

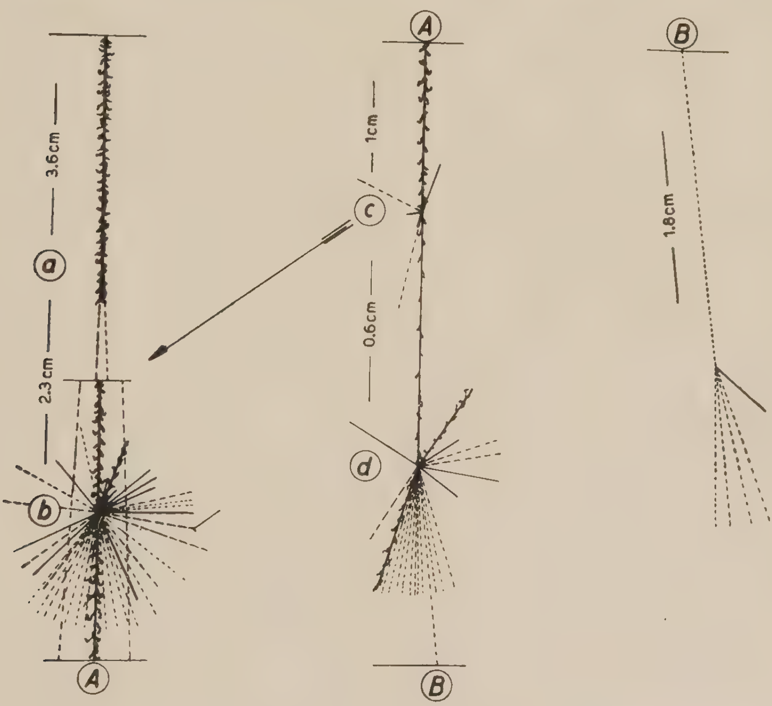

Fig. 1.

of high energy. The whole event can be followed in one plate over more than 10 cm.

The disintegrations are respectively:

a)	1 + 1 F	after a lenght of		3.64 cm;			
b)	21 + 16 F	»	»	2.3	cm	following	*a*);
c)	5 + 0 F	»	»	1	cm	»	*b*);
d)	8 + 10 F	»	»	0.6	cm	»	*c*);

One of the minimum particles from star *d*) gives rise to a star 1 + 4p, after traversing 1.8 cm.

By rapid δ-ray measurements, the charge of the primary, before and after the successive disintegrations has been estimated as follows:

$$Z = 13, \quad Z = 8, \quad Z = 5, \quad Z = 3.$$

The energy of the primary before the first interaction is estimated to at least 9 GeV/nucleon.

Nucleon-Nucleus Interactions at very High Energy. (*)

M. SCHEIN, D. M. HASKIN and R. G. GLASSER
Department of Physics, University of Chicago - Chicago (Ill.)

1. – Introduction.

Many of the very high energy stars which have been observed [1-4] in nuclear emulsions represent the collision of a single nucleon with one or more nucleons of a nucleus in the emulsion. It is a difficult problem to classify these stars as to which can be considered fundamentally nucleon-nucleon collisions and which represent interactions in which more than one nucleon of the target nucleus is involved. The criterion of the number of black and gray tracks leaving the star does not seem very adequate since in a collision which is fundamentally a nucleon-nucleon collision near the periphery of the nucleus one relatively slow particle may be emitted at a comparatively large angle and result in a rather large excitation of the nucleus, while at the energies we are considering here ($E > 10^{12}$ eV) even a collision with several nucleons may result in sufficient collimation to excite no or few fragments. Undoubtedly some of the stars which have been observed do show some characteristic features which seem comparable with the proposed theories [5, 6] of nucleon-nucleon collisions of various authors. These principally are, 1) a very small angular spread due to the collimation induced by the Lorentz transformation at these high energies (narrow showers); 2) the observed small number of particles (between 10 and 20 created particles in collision with 10^{12} eV $< E < 10^{14}$ eV; 3) two cones of particles observed, one very narrow, the other wider, due to the high angular momentum which must be involved in any except the rare central collisions. COCCONI [7] has recently proposed as a possible criterion that the quantity $N\eta^{\frac{1}{2}}$ shall not be significantly greater than 1.3, where N is the total number of particles in the shower and η is the angle containing half

(*) Supported in part by a joint program of the U.S. Office of Naval Research and The U.S. Atomic Energy Commission.

the particles. The first collision reported which completely satisfies this criterion is the S-star [1] subsequently several others have been reported [2-4].

On the other hand, it seems impossible to classify all collisions as nucleon-nucleon since most collisions in emulsion occur with silver or bromine and one may be led into grave error through analyzing stars which are not of this sort as though they were. The magnitude of this error can only be known when a good theory of the nucleon-nucleus collision becomes available.

Some authors [8, 9] have tended to classify all collisions as nucleon-nucleus and to describe the collisions by a cascade mechanism. They treat the subject by a cascade mechanism which unrealistically neglects the effect of particles which can leave the shower zone at a fairly large angle even at very high primary energies. Also these theories do not explain that most of the showers at energies $E > 10^{12}$ eV look very similar to the events which have been described as nucleon-nucleon collisions (e.g. the S-star) while others look like the stars to be described in this paper.

It is dangerous to discuss in the same manner stars covering a wide range of energies since some of the characteristics of these stars are undoubtedly sharply energy dependent. We will confine our discussion to the region of energies over 10^{12} eV, where multiple meson production is certainly a predominant feature [1, 3], and where in addition to pions heavier mesons and hyperons and possibly nucleon-antinucleon pairs are also produced.

The stars described in this paper, when combined with previous evidence, show that in considering collision within a heavy nucleus it is necessary to introduce pluro-multiple processes since the different types of showers cannot be explained by only plural or pure multiple processes, as will be discussed below.

2. – Description of Events.

The first star to be discussed is produced by a neutron. It will be designated the N-star and is shown in Fig. 1. It is of type $32+137\,\mathrm{n}$ in the Bristol notation [2]. This is the largest number of charged shower particles so far reported produced by a single nucleon. The N-star occurred in a $600\,\mu$, Ilford G-5 plate flown for eight hours at about 75 000 feet at 41° N geomagnetic latitude, under a copper block of one inch thickness. The collision is located about the middle of the plate and the shower enters the glass surface after traversing a distance of $675\,\mu$. Since this plate was at the edge of a stack the secondaries cannot be traced any further. The apparent direction of the incident neutral particle is such that it could not have come from the copper block. The incident must be neutral since it must be approximately opposite the core of the event. The closest charged particle is an α-particle

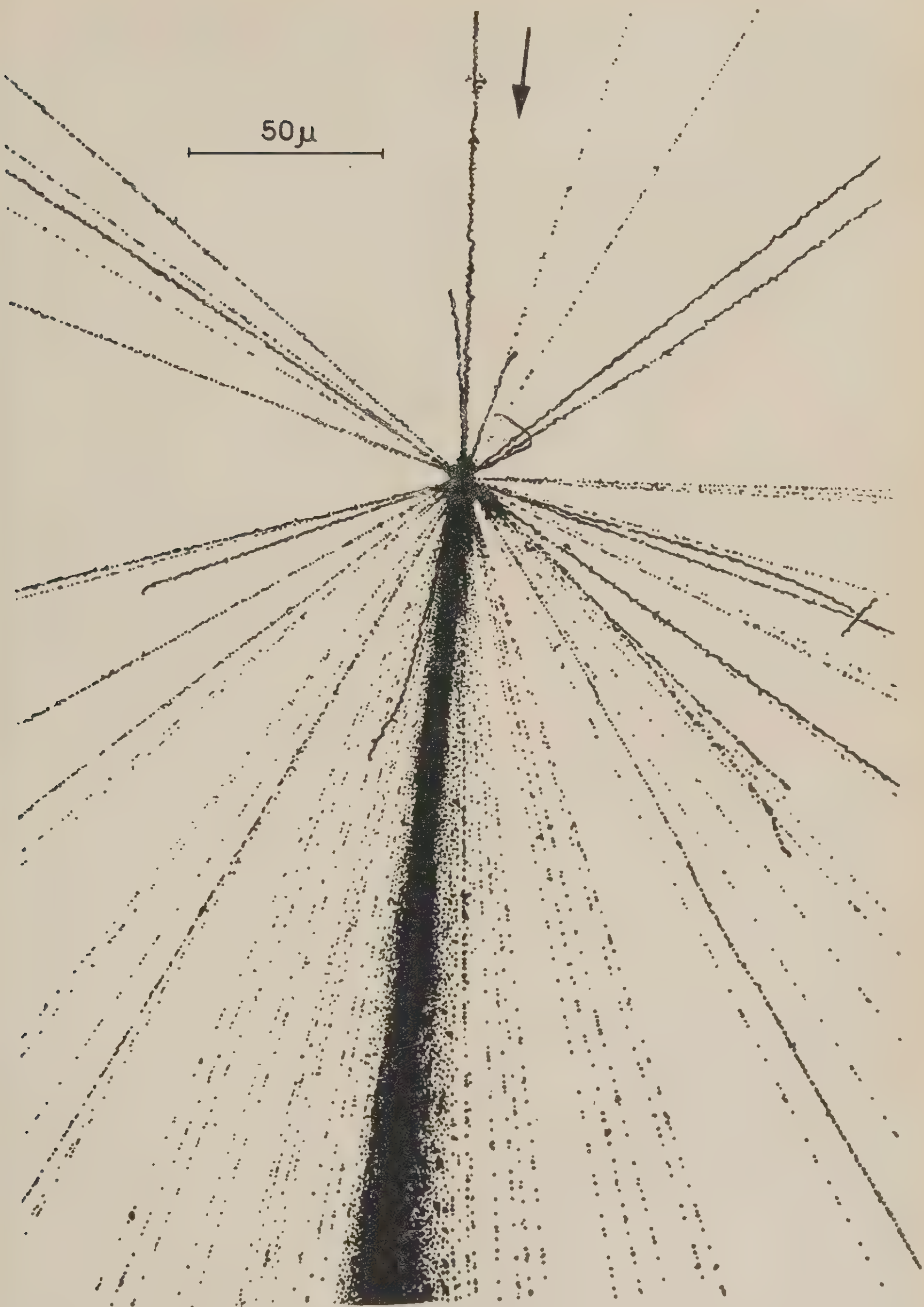

Fig. 1.

which is at an angle of more than 5 degress with the anticipated angle and is definitely not relativistic since it exhibits multiple scattering along its path and its ionization is well above that of an α-particle at minimum. An area of 20 mm² about the event was searched for possible charged particles of high energy which might trace to a common origin with the incident neutral particle without success. All angles were checked by measuring at several distances from the star on the precision scattering stage [10]. In this way the projected angles of the shower particles in the plans of the emulsion could be measured to 0.1°, while the dip angles could be measured only to an accuracy of from 1° to 3° depending on the magnitude of the angle. Thus the space angles are known with an average accuracy of 2°. For the very small angles, symmetry about the axis was assumed in computing the space angles, since the dip could not be measured to a high enough precision. At larger angles this symmetry was confirmed.

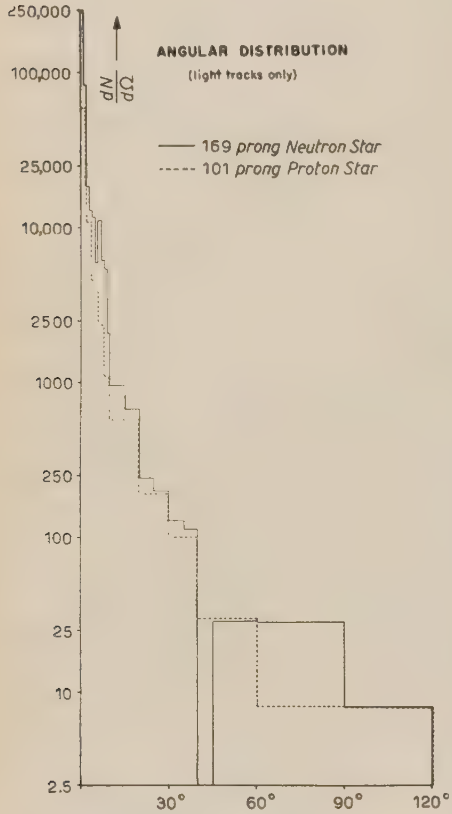

Fig. 2.

The charge of the particles producing the black and grey tracks was bracketed as well as possible with a comparison of grain density and δ-ray count. In this way it was determined that the total charge, Z, of the fragments is 40-45, which represents a conservative lower limit.

The P-star is of type 25+76 p. It occurred at the top surface of a 200 μ G-5 nuclear emulsion flown for 10 hours at 95 000 feet at 55° N geomagnetic latitude. The primary and four of the fragments were found in the adjacent plate. The secondaries in the core have a total length in the emulsion of 250 μ before entering the glass backing. No plate was beyond this one so the secondaries could not be traced any further. Using the same techniques as for the N-star the projected angles could be measured to an accuracy of 0.5°. The angular distribution is given in Fig. 2. The total charge, Z, on the fragments was determined to be between 32 and 46, in the same way as for the N-star. The thinner emulsion leads to less track length and less certainty of identification for these fragments.

3. – Discussion.

From the fact that the total charge in the fragments of the N-star was greater than 40 it is possible to infer that the nucleus which was struck was silver, since this is the only nucleus present in emulsion in any abundance with a sufficiently high Z. The P-star target nucleus could have been either silver or bromine by the same criterion, but was probably silver, also. The black and grey tracks are mostly produced by processes at energies where meson production is a very small effect, so that they can be considered to have merely arisen through an excitation of the nucleus by a relatively small amount of energy in a subsidiary process to the one which produced the shower tracks. Of the 137 shower particles in the N-star at least 130 must be created particles, since at most seven nuclear charges are available after the fragments are created. It is impossible to determine precisely what type of particle these tracks represent, of course, whether pions, heavier mesons, proton-antiproton pairs, or hyperons. It is not possible to estimate very well, therefore, the number of neutral particles which would be expected to accompany the charged particles, but it must be a sizable number since the Rochester and Bristol groups have evidence that a large fraction of the total particles are neutral [11]. Thus we have at least 130 charged particles plus some undetermined number of neutral particles being created in a collision of one nucleon with only a few target nucleons. A similar argument can be made regarding the secondaries of the P-star.

None of the proposed plural theories [8, 9, 12] predicts any numbers such as are observed here and it is difficult to see how any modification of a theory which limits the production process to one meson in each collision and yields a narrow angular distribution can ever account for such large numbers.

An essential feature of all the purely multiple theories, theories in which the production process is described as taking place in a collision between the incident nucleon and a single nucleon of the target nucleus, is that in the center of mass system of the primaries the collision may be presented as symmetric with respect to reflection in the plane perpendicular to the direction of relative motion of the two nucleons [5, 6]. In fact this property in some form or other has been the basis of most energy determinations based on such multiple theories [13]. For both the N-star and the P-star it is impossible to construct a Lorentz transformation which gives the angular distribution in the transformed system any degree of symmetry. The most obvious choice, that transformation which sends half the particles backward and half forward in the transformed system corresponds to a primary energy of only 250 GeV for the N-star and shows a marked asymmetry, with a forward cone followed by a dip around 15°, while the backward hemisphere is nearly flat. Various

other transformations gave even more asymmetry in the transformed angular distribution. Also for the multiple theories proposed so far the angular spread and multiplicity as observed in these stars are inconsistent. Fermi's theory could not predict a high enough number of particles with this angular spread. On the other hand, on Heisenberg's theory the large number of particles could only be produced in a central collision in which the symmetry principle should apply especially well. On these grounds there is strong evidence that the N- and P-stars represent events which could not be caused by a purely multiple process in a nucleon-nucleon collision.

Another star, of type $18+78\,\text{n}$, has been recently observed here also. This star differs from the above two stars in that it does not show a marked concentration of particles in the forward direction. A more extended analysis of these three stars is underway on the basis of considering the interaction of the primary with more than one target nucleon. A preliminary estimate based on these considerations gives an energy for the primary to both the N-star and the P-star of $E = 10^{13}$ eV and a somewhat lower energy for the third star mentioned above. A tentative explanation for the rarity of stars of this type is that a central collision with a heavy nucleus may be a necessary requirement.

* * *

We wish to thank E. Voltaggio and D. B. Williams for their assistance. We wish also to thank Dr. J. J. Lord (*) for his valuable cooperation in the earlier phases of work on the P-star.

(*) Now at the University of Washigton, Seattle, Washington.

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On a Star with More than 200 Shower Particles.

M. TEUCHER

Physikalisches Institut der Universität - Bern

A large star containing 221 shower particles, 23 grey and 6 black prongs has been observed in emulsion No. 2 of stack No. 13 (Madrid flight). The primary of this event shows a δ-ray density corresponding to $Z = 8 \pm 1$ and will be considered henceforth as an ^{16}O nucleus. This track has a dip of 3° 45′ (with respect to the plane of the emulsion), and can be followed through ten emulsions.

The shower leaves the stack in emulsion No. 1.

From the observed number of heavy prongs it follows that the target nucleus was either Ag or Br. The large number of grey prongs indicates that there was a central, not a glancing collision. If one assumes that all the nucleons of the ^{16}O and a Ag-nucleus have been affected by the collision, one can expect at the most 55 protons and 68 neutrons to have taken part in this process.

Since several of the observed heavy prongs seem to be α-particles, containing two protons, about 20 protons could be present among the 221 shower particles.

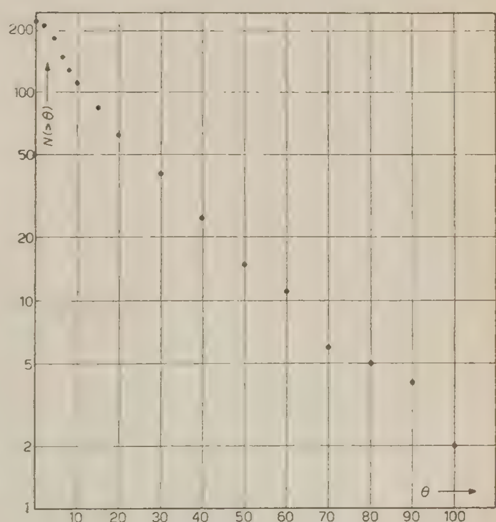

Fig. 1. – Integral angular distribution of shown particles.

Fig. 1 shows the angular distribution of the shower particles with respect to the direction of the primary. Half of these lie in a cone with

half angular opening of 10°. Fig. 2 shows a microphotograph of the event.

If one assumes that this event has been produced by the superposition of several simultaneous nucleon-nucleon collisions, one obtains an energy of 70 GeV per nucleon for the primary nucleus. This value is probably just a rough estimate, since secondary interactions in the target nucleus are highly probable. However these could not change the result by a very large factor.

Till now a track length of 138.03 cm of shower particles has been followed through in emulsions 2 and 1. Four secondary stars have thus been found, the details of which are given below:

$$9\,(1) + 2\mathrm{p}$$

$$7\,(1) + 0\mathrm{p}$$

$$15\,(4) + 2\mathrm{p}$$

$$12\,(3) + 0\mathrm{p}\,.$$

The number in parenthesis gives the number of grey prongs. These stars do not indicate a large energy of their primaries, in fact one would not obtain more than 1 GeV on the average. These observations lend additional support to the previous assertion that the energy of the primary ^{16}O nucleus, as determined by the half angle, cannot be very wrong.

The total track length of the shower particles in the stack is about 300 cm. Two of the grey prongs in the backward direction have been identified as mesons. One produces a σ-star with four prongs, the other shows $\pi \to \mu \to e$ decay.

The star described here shows a marked difference with respect to a similar event found by LAL, PAL, PETERS and SWAMY [1]. In that case a Mg-nucleus collided with (probably) a Si-nucleus of the glass. The multiplicity is of the same order of magnitude as in our case, while the energy per nucleon is greater by a factor of 100. The determination of the energy of the incoming particle by the half angle method, in the above example, is consistent with the estimate based on the energy of secondary stars.

The latter show a very different picture, with regard to the ratio of shower particles to heavy prongs, from ordinary stars; they contain less black prongs. The authors believe that there is a marked difference between meson-nucleon and nucleon-nucleon collisions. If we compare however their observations with our event, it seems that these effects are very energy dependent, in agreement with the results of DANIEL, DAVIES, MULVEY and PERKINS [2] who showed that the number of black prongs in jets decreases with increasing energy.

According to the Fermi-theory [3] the mean multiplicity in a nucleon-nucleon collision of 100 GeV is $\bar{n} = 4.5$. The Heisenberg-theory [4] leads to

Fig. 1

$\bar{n} = 13$ (including π^0-mesons in both cases) for the same energy. It seems that both theories are unable to give a satisfactory explanation of our event, even if one assumes that half of the nucleons of the ^{16}O nucleus took part in the meson production and their numbers has been further increased by secondary interactions.

The mechanism of meson production in the collision of two heavy nuclei seems to differ from the hereto theoretically considered cases of isolated nucleon-nucleon collisions in that respect that the energy dissipation is much larger. If several nucleon-nucleon collisions take place simultaneously in a very small volume, which is possible in the collision of two heavy nuclei, the interaction of the meson fields of the individual colliding nucleons seems to affect the meson production in a very pronounced way.

In the following investigations we intend to determine the energy and mass distribution of about 100 shower particles, by scattering measurements. Besides it should be possible to determine the number of π^0-mesons accurately. Thus a check of the assumptions of meson production made above should be possible.

* * *

I would like to express my gratitude to Prof. F. G. HOUTERMANS for his continuous interest and to Dr. U. HABER-SCHAIM for many stimulating discussions. The financial means for our participation at the balloon flights in Sardinia in 1953 were put at our disposal by the Swiss National Fund for Research. All our measurements would have been impossible without the Koordinatenkomparator of E. Leitz, Wetzlar.

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Questioni tecniche.

Un simple dispositif pour la mesure rapide des lacunes.

G. BARONI et C. CASTAGNOLI

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

1. – HODGSON [1] a proposé de compter les lacunes au lieu des grains pour obvier à des difficultés très serieuses relatives à l'identification des particules dans les émulsions photographiques lorsque l'ionisation est supérieure à 4-5 fois le minimum.

Durant ces quatre dernières années des travaux sur cette méthode ont été effectués par MM. O'CEALLAIGH, MENON [2], MERLIN [3], KAJAS [4], RITSON [5], DELLA CORTE [6]. On peut dire que cette méthode fort imprécise au debut, n'est pas encore bien developpée bien qu'elle ait déjà servi à l'identification des mésons lourds et de même à la différentiation des particules émis par les étoiles.

Les différents autheurs précités ont proposé les mésures suivantes à leur avis plus appropriées:

a) un dénombrement de toutes les lacunes (G);

b) un dénombrement des lacunes suffisamment longues (G');

c) une mesure de densité des lacunes, c'est-à-dire du nombre des lacunes par unité de longueur;

d) une mesure de la longueur totale ou différentielle (L o l);

e) une mesure de la longueur moyenne des lacunes ($\bar{l}$), c'est-à-dire du rapport de la longueur différentielle au nombre des lacunes.

On peut dire, aujourd'hui, que pour un examen approfondi des données expérimentales il est très difficile de choisir entre les grandeurs *a*-*e*. La véritable raison de cela réside dans la difficulté d'effectuer le dénombrement ou la mesure de la longueur totale, operations longues et surtout fort délicates.

On a réalisé un dispositif expérimental très simple qui permet d'obtenir

en même temps toutes les informations *a-c*, avec une vitesse de travail qui est de 5 à 10 fois plus grande que la normale.

2. – Selon la méthode de Ritson [5], nous avons avant tout réalisé un dispositif afin que la platine du microscope puisse avancer d'une façon continue à la vitesse de 40 μ/min. On obtient ce resultat au moyen d'un mouvement mécanique avec une démultiplication par engrenages D (Fig. 1), jusqu'à obtenir

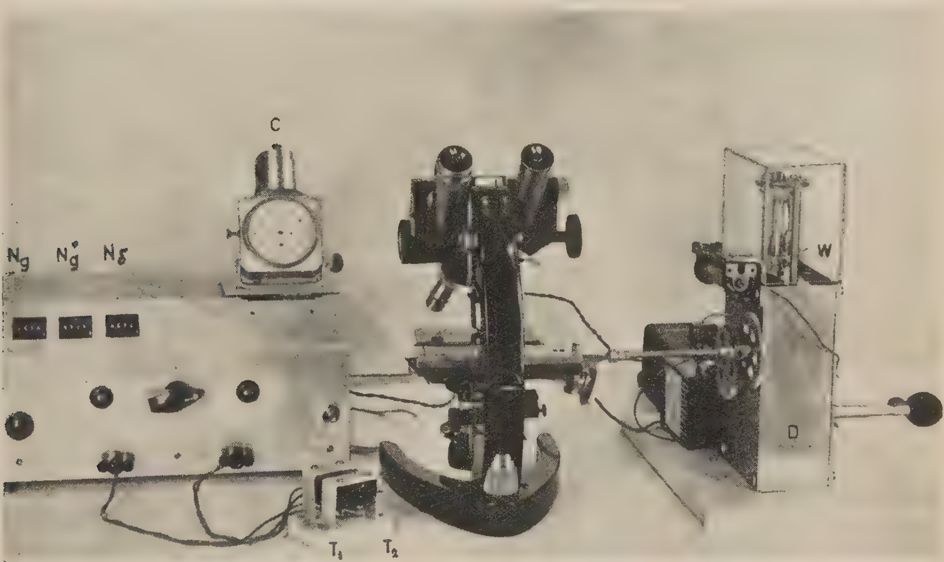

Fig. 1.

la vitesse voulue. Un régulateur de Watt W rend le mouvement uniforme. Toutes les 5 minutes, c'est-à-dire à tous les 200 μ, un contact électrique arrête le mouvement de la platine. On n'a pas utilisé un moteur électrique parce que il est presque impossible d'éliminer les vibrations.

On place la trace parallèlement au mouvement et l'on observe à partir de la fin du parcours au moyen d'un objectif 100$\times$ et un oculaire à fil fixe 20$\times$. L'observateur presse le bouton T_1 quand la lacune commence à passer sous le fil de l'oculaire et le mantient jusque à la fin de la lacune. Le bouton est relié à un simple circuit électronique (Fig. 2) et permet d'actionner en même temps:

1) un énumérateur N_g qui signale toute fermeture du circuit, c'est-à-dire qui enregistre toutes les lacunes;

2) un énumérateur N_q^* qui ne se déclenche que si la lacune a une longueur supérieure à l (l peut être réglé à volonté). On obtient cela avec un circuit de temps normal (RC avec R variable). Quand on relâche le bouton T_1 un rélais se déclenche remettant la capacité à la masse;

3) un chronomètre électrique intégrateur Jaquet (c) à 1/5 de seconde qui mesure la durée des lacunes.

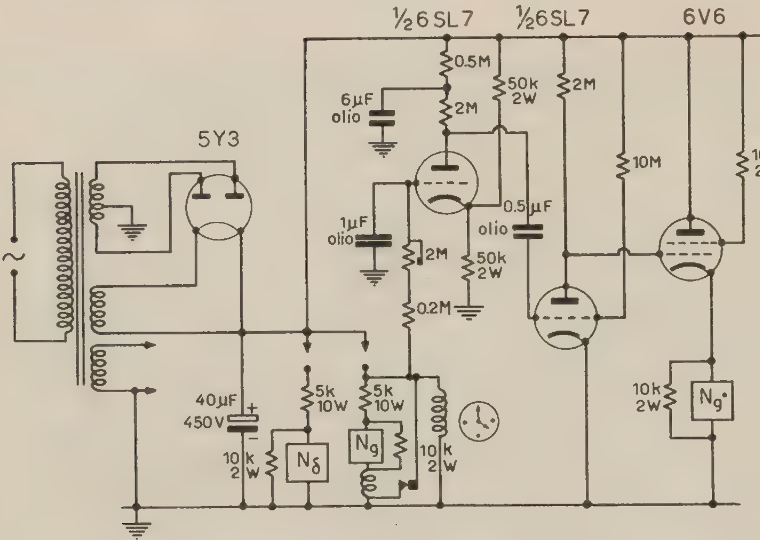

Fig. 2.

Un second bouton T_2, relié à l'énumérateur N_δ, permet de compter tous les rayons δ avec l'avantage évident de pouvoir faire en même temps des mesures de lacunes et de rayons δ sur la même trace.

3. – Quelques uns des resultats que nous avons obtenus jusqu'à présent sont representés dans les graphiques (Fig. 3 et 4) et sont relatifs à 15 mésons π, 15 protons, 2 mésons K et un triton.

Nous avons accepté seulement les trajectoires présentant une inclination par rapport au plan de l'émulsion très faible ($\leqslant 15\%$).

Un travail systématique est en cours mais il est déjà certain que grâce à ce simple dispositif et avec une économie de temps d'un facteur 5-10 on obtient des résultats très consistants entre eux et qui donnent mesures concordantes des masses des particules. Les valeurs des rapports r des masses des particules données soit par la mesure de la longueur partielle soit par la mesure totale sont précises; l'inclinaison des courbes obtenues par nous s'accorde très bien avec celles des autres Auteurs. Par exemple, en supposant

valides des lois du type

$$G = AR^q \qquad \left(\begin{array}{l} R = \text{parcours restant} \\ A,\ B = \text{const.} \end{array}\right)$$
$$L = BR^p$$

pour le nombre totale et la longueur totale des lacunes en fonction du parcours on obtient pour p et q les valeurs données dans la Table I.

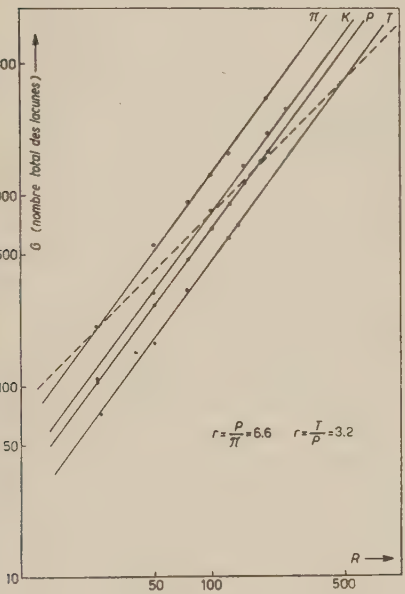

Fig. 3.

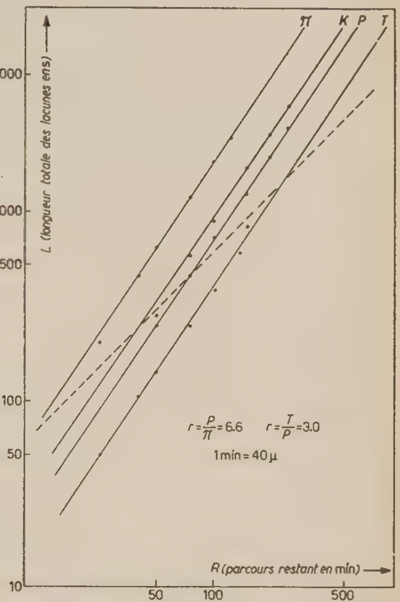

Fig. 4.

Nous avons aussi mesuré la masse des deux mésons K trouvés dans notre laboratoire (K-Ro$_3$, K-Ro$_4$) obtenant des valeurs qui sont en parfait accord avec ceux des méthodes ionisation-parcours et scattering-parcours. Nous avons aussi verifié la masse du tritôu par des mesures de scattering.

TABLE I.

Auteurs	p	q
HODGSON [1]	1.45	—
KAYAS [4]	—	1.32
BARONI et CASTAGNOLI	1.43	1.29

Le travail qui en ce moment est en cours tend à obtenir des courbes d'étalonage toujours plus précises pour une meilleure évaluation de masses et

tend à étudier d'une façon critique l'influence de différents paramètres, surtout le développement des plaques et l'inclinaison des traces, en tirant parti de toutes les possibilités de la méthode.

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Mass Determination on Steeply Dipping Tracks in Emulsion Block Detectors.

S. Biswas, E. C. George, B. Peters and M. S. Swamy
Tata Institute of Fundamental Research - Bombay

In the study of particle tracks in Emulsion Block Detectors one can frequently observe appreciable length of trajectory even for those tracks which traverse individual emulsion sheets with a large dip angle. The customary methods for deducing the mass of such particles from multiple Coulomb scattering and range or from multiple Coulomb scattering and grain density give very unreliable results. The failure of obtaining accurate mass values with these methods is due to the small distortions which are introduced into the emulsions during processing. We will show in this paper that the effect of such distortions can be completely eliminated if instead of deducing the Coulomb scattering from second co-ordinate differences one makes use of third or higher order differences. In a small sample of proton tracks with dip angles between 32° and 52° good mass determinations have been made.

The Relation Between Second, Third and Fourth Order Co-ordinate Differences.

If P_k designates points located on the track and separated from each other by the cell-length t, and if y_k denotes the distance to the point P_k from a line nearly parallel to the track then the second difference D_2 is customarily defined by:

$$D_2^{(k)} = y_k - 2y_{k+1} + y_{k+2} \, .$$

Similarly we define the third difference D_3 by:

$$D_3^{(k)} = y_k - 3y_{k+1} + 3y_{k+2} - y_{k+3}$$

and in general the difference D_n by:

$$D_n^{(k)} = \sum_{\lambda=0}^{n} a_\lambda y_{k+\lambda}$$

with

$$a_\lambda = \frac{n!\,(-1)^\lambda}{\lambda!\,(n-\lambda)!}\,.$$

One can then easily show on the basis, for instance, of the distribution function given for D_2 by SCOTT [1], that the mean absolute values of the second, third and fourth differences are related as follows:

$$\langle |D_2| \rangle = \Delta$$

$$\langle |D_3| \rangle = \sqrt{\tfrac{3}{2}}\,\Delta$$

$$\langle |D_4| \rangle = 2\Delta$$

and that in the approximation in which the distribution function of D_2 is taken to be a Gaussian, the distribution functions for the higher order differences will also be Gaussian.

It is easily seen that while D_2 measures the deviation of the track from a straight line, D_3 measures its deviation from a circle of arbitrary radius, and D_4 measures its deviation from a curve whose curvature varies linearly. The Δ-values obtained from measurements of D_3 will, therefore, be independant of a uniform curvature and those of D_4 independent of a uniformly varying curvature irrespective of whether this curvature is introduced by distortion of the emulsion or by waviness of the microscope stage.

The customary curvature correction which is made by adding to each of the experimentally determined second difference values (D_2) a constant, such that their algebraic sum vanishes, is a satisfactory approximation for long tracks, but quite inapplicable to steep tracks where the number of available cells per emulsion sheet is very small. It represents an over correction since even for an undistorted track the algebraic sum of second differences should not vanish except in the limit of a very large number of readings.

The Effect of Distortion on Scattering Measurements.

The most common distortion in emulsions consists of a displacement S in the plane of the emulsion (x, y plane) whose direction and magnitude remains constant over large areas of the plate, but increases quadratically

with depth (Z direction), having the value zero at the glass surface and the maximum value S_0 at the air surface of the processed emulsion. One can easily show that under these conditions the contribution of the distortion to the measured second differences (δ_2) is given by:

$$\delta_2 = \frac{2S_0}{N^2} \sin \alpha ,$$

where N is the total number of cell-lengths available for measurements in the particular emulsion sheet and α is the angle which the projection of the track in the x, y plane makes with the distortion vector $\boldsymbol{S}$. Thus even if the distortion is moderate ($S_0 \leqslant 20\ \mu$) in a 600 μ emulsion a steep track for which only four or five cell-lengths are available can give spurious second differences of the order of 1 μ, which is equal to or more than the expected scattering per cell-length. On the other hand the contribution of this type of distortion to the third difference will be smaller by a factor of the order of $(1/N)(S_0/l_0)^2$ where l_0 is the projected track length in the emulsion sheet. Assuming the same emulsion thickness and distortion as before, for a track which traverses the emulsion with a dip angle of 45°, this factor is of the order of 1/3 000.

We expect, therefore, that for steep tracks in moderately distorted emulsions the scattering measured by third and higher order differences will give identical mass values but will differ substantially from those obtained from second order differences.

The Effect of Noise.

Before making a comparison with experiment, it is necessary to investigate how the emulsion noise, and noise due to reading errors must be taken into account when third or higher order differences are used for mass determination. (As mentioned before the contribution of stage noise will be negligible in third order differences) (*).

Experimentally the noise contribution can be easily determined by measuring second, third and higher order differences on the flat track of a very energetic particle. It is also possible to calculate the noise distribution on the basis of some model and determine the expected mean absolute values of ε_2, ε_3, etc.. It turns out that the theoretical distribution function is not very sensitive to the details of the model of noise which is used. We made have calculations for instance, on the basis of the following assumptions.

(*) Noise in the focussing motion (z-motion) of the microscope can be neglected for measurements on flat tracks, but will affect scattering measurements on steeply dipping tracks and may have to be taken into account.

The probability of making a grain developable is proportional to the length of particle trajectory which lies inside the grain. The grains have spherical shape, are of uniform size and uniformly distributed in the emulsion. A reading represents the average y-co-ordinate of the centres of the small number of grains (for instance, 5 grains). Readings can only be made in discrete steps which (in appropriate units) are represented by the possible values: 0, ± 1, ± 2, ± 3.

With such a model the predicted ratios $\varepsilon_2 : \varepsilon_3 : \varepsilon_4 : \varepsilon_5$ are in excellent agreement with the experimental values and furthermore, the distribution function of the noise resembles a normal distribution sufficiently closely to justify the commonly used relation between the « measured » scattering values D_n and the « true » scattering values Δ_n:

$$\Delta_n = \sqrt{D_n^2 - \varepsilon_n^2}\,.$$

Experimental Results.

By measuring flat tracks due to very energetic particles for which scattering may be considered to be negligible compared to noise, we obtain the following mean absolute values for differences in various orders:

$$\varepsilon_2 = 0.156\ \mu, \qquad \varepsilon_3 = 0.285\ \mu, \qquad \varepsilon_4 = 0.526\ \mu, \qquad \varepsilon_5 = 0.997\ \mu\,.$$

These noise values were used in Table I to derive, from the « measured » differences D_n, the corresponding « true » differences Δ_n.

TABLE I.

Particles	Scattering scheme [2]	Second Differ.		Third Difference			Fourth Difference		
		No. of cells	Δ_2 (μ)	No. of cells	Δ_3 (μ)	$\sqrt{\frac{2}{3}}\Delta_3$ (μ)	No. of cells	Δ_4 (μ)	$\Delta_4/2$ (μ)
10 flat π-mesons	π (1.6)	807	1.605 ± .042	746	2.030	1.657	686	3.388	1.694
12 flat Protons	p (1.6)	779	1.600 ± .045	741	2.061	1.680	712	3.395	1.698
6 flat protons	π (1.6)	890	0.712 ± .019	869	0.932	0.760	840	1.522	0.761
11 dipping protons (5 with $45° < \theta < 52°$) (6 with $32° < \theta < 45°$)	π (1.6)	764	0.924 ± .026	635	0.925	0.756	519	1.488	0.744

In order to correct for the effect of large angle single scattering individual values of D_n which exceed four times the average of the remaining values have been eliminated. The first line in Table I represents results of making measurements on

the tracks of ten flat π-mesons, using the method of varying cell-length [2] (π (1.6) scheme). These cell-lengths are so chosen that, irrespective of range, the mean absolute value of the second difference for π-meson is expected to be 1.6 μ. The second and third lines represent the result of measurements on flat proton tracks, scattered according to the p(1.6) and π(1.6) schemes, respectively. In each case about 800 readings have been obtained. The Table shows that the values obtained for Δ_2, $\sqrt{\frac{2}{3}}\Delta_3$ and $\frac{1}{2}\Delta_4$ are identical within experimental errors and give the correct mass values for the particles whose tracks have been measured. There is, however, an indication that slightly better agreement between the results from second, third and fourth order differences can be obtained if the theoretically derived conversion factors ($\sqrt{\frac{2}{3}}$ and $\frac{1}{2}$) are decreased by about 6%. The fourth line of Table I represents the results of measurements on protons which traverse the emulsion stack with dip angles between 32° and 52°. Here we find that as expected the results obtained from third and fourth differences are identical with each other and with values obtained for flat tracks. The values derived from second differences on the other hand are quite different for steep and for flat proton tracks.

Since the mass of a particle varies as $\Delta^{-2.276}$ [2] the application of second difference measurements to steep tracks gives for the dipping tracks a mass value which is too low by a factor $(.924/.712)^{2.276} = 1.8$ but the application of third and fourth difference measurements gives factors of 0.98 and 0.90 respectively.

We have purposely omitted to indicate the standard deviation in the results obtained from third and fourth order differences. Individual measurements of Δ_3 and Δ_4 are not strictly independent of each other and the number of tracks we have measured so far is as yet insufficient to derive an empirical estimate of the error from the internal consistency of the data.

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Stage Noise and Spurious Scattering. Reversing Sagitta Method.

J. K. Bøggild and M. Scharff

Institute for Theoretical Physics of the University - København

Measurements, using an adaption of the sagitta method (*), of stage noise and spurious scattering, have been made on two Leitz Ortholux microscopes and on one of the new Koristka microscopes (Large Microscope for Nuclear Measurements, M.S.2) recently delivered to the Institute. The method we have applied utilizes the excellent Koristka 55 × objective with a long working distance of 1.35 mm which makes it possible to examine tracks in emulsions through the glass, provided that the thickness of this is not more than one mm. The displacements were measured by means of an eyepiece micrometer with a movable hairline. Using the Koristka 55 × objective the divisions on the graduated drum of the Leitz eyepiece micrometer and of the Koristka eyepiece micrometer correspond to 0.054 and 0.10 μ respectively. The displacements were read to the nearest half division on the Leitz device, corresponding to 0.027 μ, and to the nearest fifth of a division on the Koristka, corresponding to 0.020 μ.

The use of a micrometer eyepiece makes it possible to perform scattering measurements quickly and with high precision, provided that the eyepiece is sufficiently rigidly mounted. Since the binocular tube of the Ortholux is rather unstable, these microscopes were rebuilt as shown in Fig. 1, where the eyepiece is seen to be supported by a rigid brass arm attached directly to the stand. This arrangement makes it possible to turn the drum without causing movements of the eyepiece with respect to the object. The movement of the stage was generated by a micrometer screw with a non-rotating extension of the spindle.

The Koristka M.S.2 was found to be particularly well constructed in this respect, and very useful for high precision work.

The track of a heavy primary (Li or Be nucleus), or alternatively, a scratch

(*) P. H. Fowler: *Phil. Mag.*, **41**, 169 (1950).

in a glass plate made by the grating machine in Stockholm, was used to study the noise.

The series of displacements as measured by the sagitta method is a compound of the stage movement and the track shape; however, a separation of the two contributions can be made by making two series of readings, one with

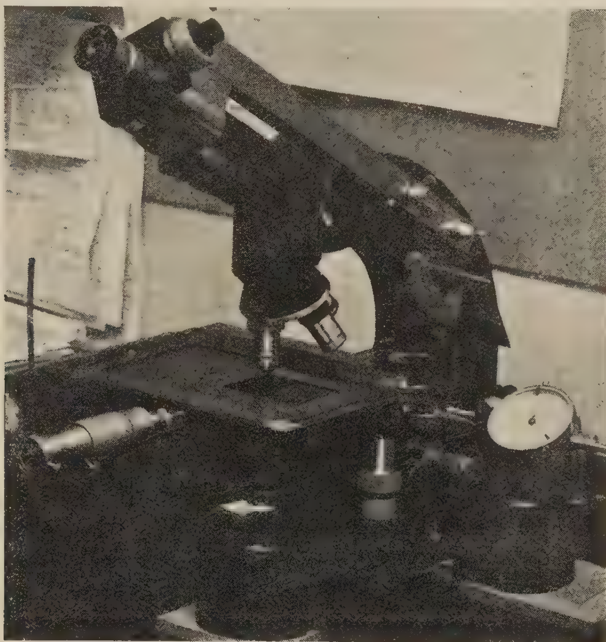

Fig. 1

the emulsion side up, and one with the glass side up. The corresponding readings of the two series should be made at exactly the same point on the track, which is so adjusted on the microscope stage that they also correspond to the same readings on the stage micrometer screw. The iron plate supporting the photographic plate and the magnetic lock of the Koristka M.S.2 facilitate putting the object to be observed in the desired position, and similar, but more primitive, facilities were made for use on the Ortholux stage. Subjective reading errors were reduced by repeating the series of readings three times.

Fig. 2 shows the apparent shape of the track measured on one of the Ortholux microscopes with the emulsion side up (curve A) and with the glass side up (curve B). Since the shape of the track is reversed by turning the plate upside down, the mean sum of the curves gives the shape of the stage movement (curve $(A+B)/2$ of Fig. 3) and the mean difference gives the shape of the track (curve $(A-B)/2$).

All the curves in the following figures have been obtained by this technique (reversing sagitta method) and thus represent either mean sum curves orm ean difference curves giving information about stage and track characteristics respectively).

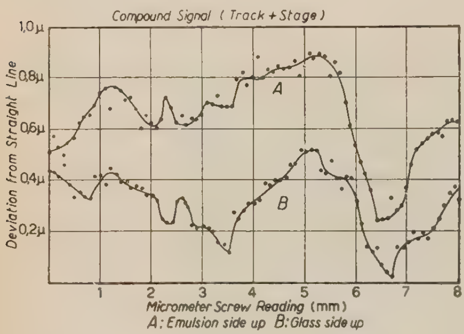

Fig. 2.

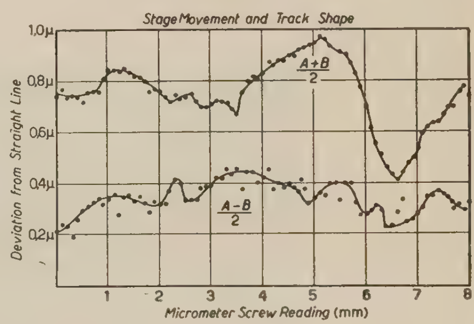

Fig. 3.

It appears from Fig. 3 that the scattering of the points about the upper curve is considerably smaller than that about the lower curve. This demonstrates that by the reversing technique the grain noise is removed from the determination of the stage movement.

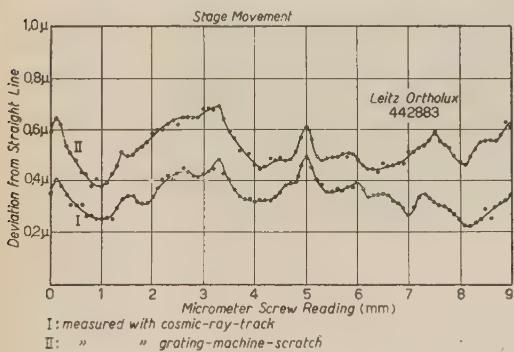

Fig. 4.

Fig. 4 shows part of the stage movement for the other Ortholux as measured by means of the cosmic-ray track and six months later by the grating machine scratch. It will be seen that the stage movement is very reproducible.

The stage movement of the Koristka M.S.2 is shown as curve I of Fig. 5. Unfortunately there was an eccentricity in the micrometer screw causing periodic displacements of more than 0.2 μ in phase with the revolutions of the screw. A temporary improvement was effected by removing the springs which hold the stage against the extension of the micrometer screw. Without the springs the stage can be utilized only when it is pushed beyond the centre position by the screw. Curve II of Fig. 5 demonstrates that the large periodic motion has vanished; there remains however, a periodic displacement of smaller amplitude, and period one mm, corresponding to two complete rotations of the micrometer screw. Curve III shows similar measurements on the gratings machine scratch. Curves II and III also show that the stage movement, when used without springs,

has, besides the small periodic error, a slight curvature. The measurements on the Koristka M.S.2 reproduced in the following figures have all been made with the springs removed.

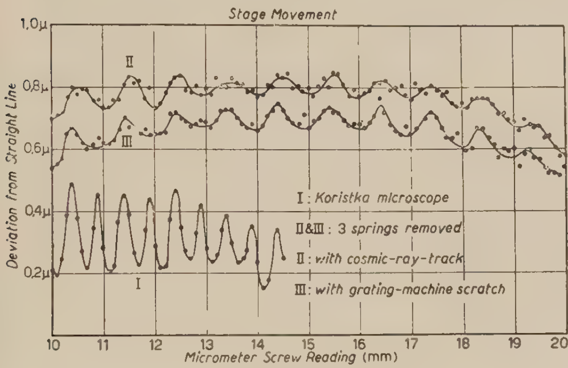

Fig. 5.

The shape of another part of the cosmic ray

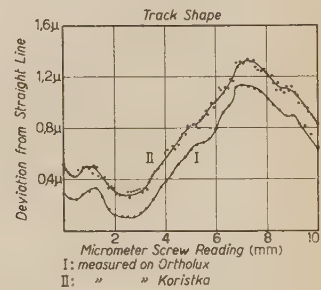

Fig. 6.

track determined by the reversing technique is shown in Fig. 6. Curves I and II were measured on an Ortholux and on the Koristka M.S.2 respectiv-

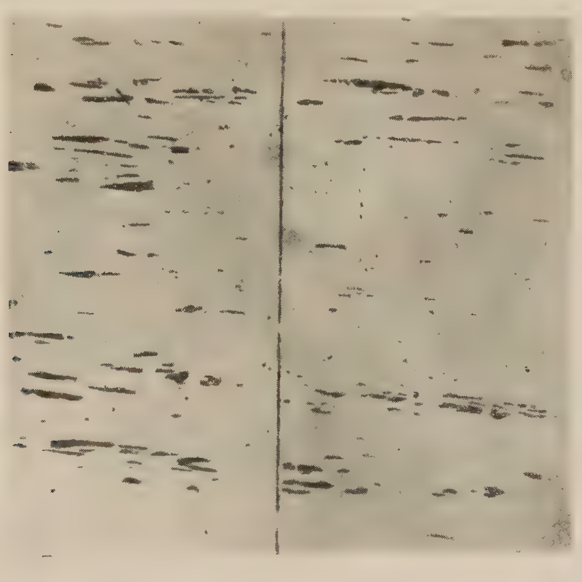

Fig. 7.

ely. It will be seen that in spite of the imperfections in the stages the curves are almost identical.

The grating machine scratch was made suitable for measurement by a thin evaporated aluminium layer, which was later cautiously removed with a rubber

eraser, rubbing across the scratch. The major part of the aluminium in the scratch remained and gave thus the line the contrast and appearance of a heavy cosmic ray track. A microphotograph of the scratch is shown in Fig. 7.

Measurements on the shape of the scratch were carried out on an Ortholux and on the Koristka M.S.2 and the results are reproduced in Fig. 8.

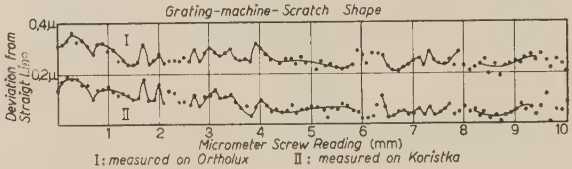

Fig. 8.

The similarity of the two curves indicates that the scratch shape has a reproducible structure, which is most likely due to irregularities in the aluminium filling. Nevertheless, the scratch deviates from a mean straigth line by not more than 0.05 μ at any point.

Statistical Analysis.

From the calculated values of the mean sum, as plotted in Fig. 3, 4 and 5, it is possible to compute the mean second difference, $|D|$, for different cell-sizes, and thereby to obtain a statistical analysis of the stage noise. The results

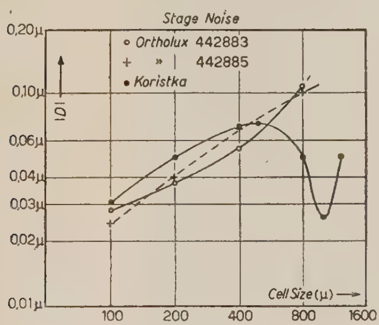

Fig. 9.

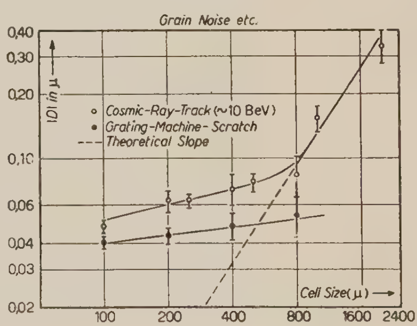

Fig. 10.

are shown in Fig. 9. The abscissa is cell-size and the ordinate mean second difference. The stage noise of the two Ortholyx microscopes is seen to be rather similar and is found to increase from 0.028 μ in 100 μ cells to about 0.1 μ in 800 μ cells. The stage noise of the Koristka M.S.2 has quite different characteristics. It is found to increase with the cell-size to a maximum of

0.072 μ in 500 μ cells, after which it decreases to a minimum for 1000 μ cells, thereafter increasing again. This behaviour is in good accord with that to be expected from the periodicity of the stage motion, which has been mentioned above.

In Fig. 10 the observed values of the mean second differences, D as taken from the mean difference curve, are plotted as a function of cell-size for the cosmic ray track (upper curve) and the grating machine scratch (lower curve). The cosmic ray track shows a genuine scattering signal in the larger cell-sizes, and a slowly rising spurious signal in the lower cell-sizes, which is believed to be mainly due to the random distribution of the grains about the track of the particle. Comparison with the curves in Fig. 9 shows that the stage noise in all small cell-sizes ($< 200\ \mu$) is much smaller than the grain noise, and hence of minor importance. The stage noise of our two Ortholux microscopes rises comparatively rapidly with the cell-size ($\sim t^{\frac{3}{2}}$), but since it can be measured, and is known to be reproducible, it is possible to apply corrections or to eliminate it entirely by using the technique described above.

The « spurious scattering » of the grating machine scratch is seen to be smaller than that of true tracks in nuclear emulsions, and the extreme straightness of the scratch makes it particularly easy to line up on the microscope stage.

Conclusions.

1) Using the reversing sagitta method it is possible to determine stage noise without refined optical equipment, provided that an eyepiece micrometer can be mounted sufficiently ridigly.

2) The cosmic ray tracks used in such studies need not be extraordinarily straight (nor does it matter if they are distorted).

3) It is probable that scratches in glass plates can be made straight enough to enable a fast study of stage noise to be made without the use of the reversing sagitta method, provided that the scratch has been proved to be suitable.

4) It is possible to measure the scattering of high energy tracks, in spite of rather large stage noise, by the reversing method. The glass backing at present in use for the stripped emulsions is unfortunately too thick for the Koristka 55× objective.

5) The analysis of the new large Koristka microscope M.S.2 has demonstrated this to be exceedingly well constructed and very useful for high precision work.

The authors wish to thank Professor M. SIEGBAHN and Engineer L. LUNDIN of the Nobel Institute for Physics, Stockholm, for their kindness in giving us two glass plates with scratches made by the grating machine.

Note added. – Since the meeting in Padua the authors, by courtesy of the firm Fratelli Koristka, Milan, have been allowed to study the action of an improved micrometer screw operating on the stage of a second Koristka M.S.2 microscope. Interferometer measurements as well as preliminary tests by our method have demonstrated that the improvement of the coupling between the screw and the stage has been successful, and we expect that the exchange of the original micrometer screw with one of the improved type will place at our disposal an instrument where the stage noise in all commonly used cell-sizes is considerably smaller than the grain noise of the tracks observed in photographic emulsions.

Calibration of the Constant Sagitta Method.

M. Di Corato, D. Hirschberg and B. Locatelli

Laboratoire de Physique Nucléaire de l'Université Libre de Bruxelles
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

We have used the constant sagitta method described in [1-3], to measure 46 tracks of π-mesons and 19 tracks of protons at the end of their range.

The π-mesons were selected from among complete π-μ decays and σ-events in which the σ-star had 2 or more prongs.

The protons were distinguished from deuterons and tritons by gap counting in the interval from 6 to 8 mm from the end of their range.

The lengths of the tracks selected for measurement were

$$8\,000\ \mu \leqslant R_p \leqslant 20\,000\ \mu\ , \qquad (\bar{R}_p = 12\,000 \text{ for protons});$$

$$200\ \mu \leqslant R_\pi \leqslant \ \ 7\,000\ \mu\ , \qquad (\bar{R}_\pi = \ \ 4\,900 \text{ for } \pi\text{-mesons}).$$

The basis cells used for the π-mesons were the set of half π-cells of (1) and for the protons we used a set of cells of twice this length.

The mean sagittae (D^*) of the π tracks were corrected for dip ($D = D^* \cos^{0.92} \psi$) [1]; the corresponding correction for the protons was found to be negligible, due to the greater length of the tracks. For each track the second differences for the single ($D_2(t)$) and for the double cells ($D_2(2t)$) were cut off at 4 times the mean value. The noise was eliminated according to

$$D_2^2 = \frac{D_2^2(2t) - D_2^2(t)}{7}\ .$$

The mean noise level was

$$\varepsilon_p = (0.145 \pm 0.005)\ \mu\ ; \qquad \varepsilon_\pi = (0.140 \pm 0.005)\ \mu\ .$$

After correction for the variation of the range-energy exponent and of

the scattering constant, and for the non equality of energy and $p\beta$ at high values as indicated in [1] we found the mean values of D_2 reduced in each case to the π-cells: ,

$$\bar{D}_2 = (0.224 \pm 0.005)\,\mu \qquad \text{for protons,}$$

$$\bar{D}_2 = (0.482 \pm 0.007)\,\mu \qquad \text{for } \pi\text{-mesons.}$$

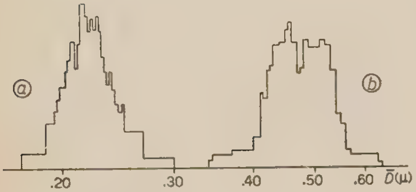

Fig. 1. – Curve *a*): protons. Curve *b*): π-mesons.

From which we obtain the mass ratio

$$\frac{M_p}{M_\pi} = 6.20 \pm 0.4\,,$$

which may be considered satisfactory.

The scattering constant calculated from the experimental values of $\bar{D}_2$ both for protons and π-mesons are by 12% in excess of the theoretical values.

The errors given have been calculated from the distribution of the experimental values of D_2 (Fig. 1) and correspond to

$$\frac{\delta D_2}{D_2} = 1.57/\sqrt{N} \quad \text{for protons;} \qquad \frac{\delta D_2}{\bar{D}_2} = 1.84/\sqrt{N} \quad \text{for } \pi\text{-mesons}.$$

(N = number of basic cells) which are greater than corresponding values as indicated by D'ESPAGNAT [4]

$$\frac{\delta \bar{D}_2}{\bar{D}_2} = 1.24/\sqrt{N} \quad \text{for protons;} \qquad \frac{\delta \bar{D}_2}{\bar{D}_2} = 1.13/\sqrt{N} \quad \text{for } \pi\text{-mesons.}$$

For the proton tracks, the $D_2(2t)$ have been calculated using independent and also overlapping cells. The distribution with overlapping cells ($\lambda = 2$) seems to be narrower (cf. Fig. 2).

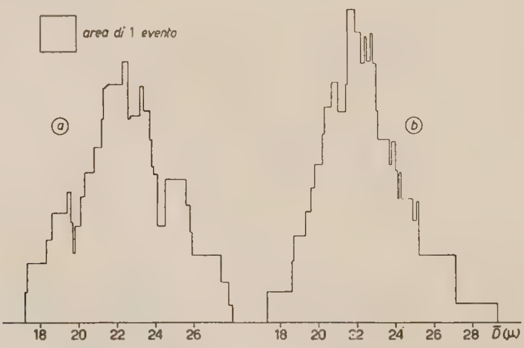

Fig. 2. – Curve *a*): independent cells. Curve *b*): overlapping cells ($\lambda = 2$).

We calculated, for the protons, the values of $D_2(3t)$ eliminating the noise between the set of basic cells and a set of treble cells. As could be expected from the fact that distorsion does not affect the flat tracks selected, we found and excellent agreement between both values obtained

$$(0.224 \pm 0.005)\ \mu \quad \text{and} \quad (0.225 \pm 0.005)\ \mu\,.$$

We have checked the constancy of the $D_2(2t)$ with independent cells: for our present data this constancy seems to be verified within the limits of the experimentals errors (cf. Fig. 3).

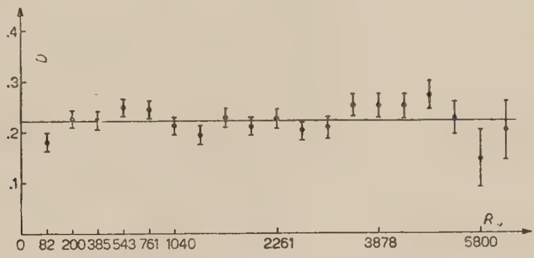

Fig. 3. – Sagitta (D) versus range (R) (D and R in μ). (19 proton tracks).

Since the π-tracks we selected were flat and so unaffected by distortion in the plates, we calculated the values of the third differences in order to obtain a calibration of this method for its later use on distorted tracks. Noise was eliminated between single and double cells as before, and the quantity D_3 calculated from the formula:

$$(D_3)^2 = \frac{\bar{D}_3^2(2t) - \bar{D}_3^2(t)}{(3/2)\cdot 7}$$

which on undistorted tracks should be equal to D_2.

A block cut-off was applied by eliminating all third differences associated with second differences such that $D_2(2t) > 4D_2(2t)$.

The values obtained were

$$D_3 = (0.236 \pm 0.006)\ \mu \quad \text{for protons}\,,$$

$$\bar{D}_3 = (0.491 \pm 0.012)\ \mu \quad \text{for } \pi\text{-mesons } (*),$$

in both cases slightly higher than the corresponding second differences.

(*) Calculated on 18 tracks only.

The elimination of the noise between the treble cells and the fundamental cells has been checked for the proton group and leads to the same value, i.e.

$$D_3 = (0.236 \pm 0.006)\ \mu .$$

More measurements on flat tracks are being made to find out whether the discrepancy between the values of D_2 and D_3 is significant, in view of the application of the method of third differences to the measurement of dipping tracks.

The work is being pursued with further measurements on dipping tracks.

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Measurements on Multiple Scattering of Stopping Particles (*).

R. G. GLASSER

Department of Physics, University of Chicago - Chicago (Ill.)

The attempt to clarify the nature and relationships of the various heavy mesons has led to a renewed attack on some of the methods of mass determination of particles in photographic emulsion which had been neglected since the artificial production of pions made possible powerful techniques combining emulsions with other instruments. These methods normally use the range as one parameter of the two parameter system needed to specify the mass of a particle. The other parameter is then either photometric track density, gap number density, gap length density, or multiple Coulomb scattering. The latter method is probably not capable of giving as precise statistical information as are some of the others, but it has the advantage that it is not as subject to systematic error due to plate condition at the time of the event as are the other methods. For this reason it is desirable that the method be developed to the fullest extent, since one can then eliminate several sources of error in identification and measurement of these new mesons. Also the data in this field is sparse enough and the postulated types of meson numerous enough that independent mass estimates by different methods on the same tracks are valuable.

LATTIMORE [1] was the first to use multiple scattering techniques for mass measurement of pions. BISWAS, GEORGE and PETERS [2] have recently proposed a scheme of mass measurement which depends on assuming that the range energy relation is known enough well to be depended on for stopping particles and that the scattering formula is given at all energies by the theory. Since this has not been given a precise experimental check, an experiment was performed which would provide reliable data on the multiple scattering versus range relation.

(*) Supported in part by a joint program of the U.S. Office of Naval Research and the U.S. Atomic Energy Commission.

Protons scattered off a beryllium target in the beam of the 450 MeV University of Chicago synchrocyclotron were bent first in the cyclotron fringing field and then in a «steering» magnet at a current corresponding to a proton energy of 57 MeV. The beam then entered an Ilford G-5 emulsion, where many of the protons stopped. This gave a large number of stopping protons for measurement which were unambiguously identified, which can be done only with considerable difficulty in plates exposed to cosmic radiation.

100 of these protons which stopped in the emulsion and were longer than 3 000 μ were chosen for measurement. The criterion of long length for the protons does not bias the results since only the scattering in the plane perpendicular to the emulsion surface affects the probability of the protons remaining in the plate until they stop, and this is independent of the scattering in the plane parallel to the emulsion. For simplicity of measurement and treatment of the data, multiple scattering was measured at 50 μ cell lengths from the end of the track to a point 2 500 μ from the end, by the coordinate method, on the precision stage which has been described previously [3]. The scattering was then determined at each point by taking half the second difference of the coordinates, η (that is, $\eta_i = y_i - (y_{i-1} + y_{i+1})/2$). The average over all protons of the absolute value of η is then computed at each value of R with the usual cut-off at four times the mean and plotted as a function of R, as shown in the lower section of Fig. 1. The noise level was found to be very low; however corrections for noise have been made to the points in the figure. The relation between $\overline{|\eta|}$ and R is found by a least squares fit to the logaritms of the experimental quantities. Its equation is given as

$$\overline{|\eta|} = (18.9 \pm 0.1) R^{-(.607 \pm .002)} . \tag{1}$$

This formula differs rather significantly from the formula obtained by combining the best semi-empirical range energy relation with the assumption that the scattering constant is always equal to the accepted value of 25. This curve, the equation of which is

$$|\eta| = 15.7\, R^{-.595} \tag{2}$$

is represented by the dashed line in the figure. The reason for the difference may lie in the fact that, first, the actual path length is longer than the chord length due to the scattering itself and second, the scattering constant varies from the theoretical value at low energy. The first of these reasons is supported by the fact that the difference between the curves decreases at large residual range.

In order to arrive at the mass dependence of this formula we can use the following reasoning. The multiple scattering formula can be written to a good approximation in the form $|\eta| = f(v) t^{\frac{3}{2}} M^{-1}$, where t is the cell length in

microns, $f(v)$ is a function only of velocity, and M is the particle mass. The range energy relation can be written in the form $R = Mg(v)$, where $g(v)$ is another function of velocity only. Combining the two one obtains $\overline{|\eta|} = M^{-1}k(R/M)$. Thus, if for protons as shown above we can represent the scattering by $\overline{|\eta|} = KR^{-n}$, then the more general relation follows $\overline{|\eta|} = KM^{n-1}R^{-n}t^{\frac{3}{2}}$. Inserting the values obtained from the proton measurements and applying the formula to an arbitrary particle

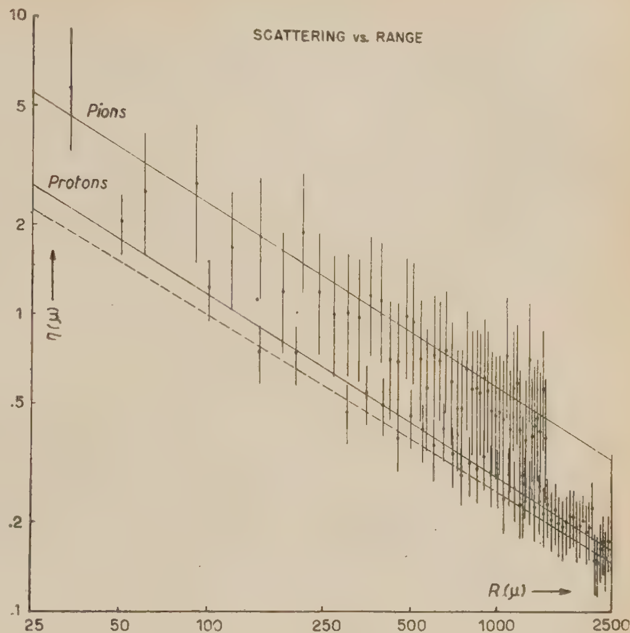

Fig. 1.

$$\overline{|\eta|} = (18.9 \pm 0.1)R^{-(.607\pm.002)}\left(\frac{M}{M_P}\right)^{-(.393\pm.002)}\left(\frac{h}{50}\right)^{\frac{3}{2}}, \tag{3}$$

where M_P is the proton mass; the 50 in the denominator of the cell length dependence comes from the cell length used in the proton measurements.

The validity of this relationship was checked by measuring the multiple scattering on the tracks of 20 π^+ endings in a plate exposed to the 46 MeV pion beam of the University of Chicago synchrocyclotron. Each pion was identified by its $\pi\to\mu\to e$ decay scheme. The results of these measurements, with a cell length of 30 μ, are shown in the figure. Since the proton and meson points should overlap, the values of $\overline{|\eta|}$ for each meson point have been multiplied by two in the figure. By substituting the pion mass and the cell length used in equation (3), the formula

$$\overline{|\eta|} = 18.5\, R^{-.607} \tag{4}$$

is obtained and is drawn in the figure. As can be seen, it passes through the points and is a very good fit. This was checked by forming the least squares best fit to the pion points. The fact that the error on the meson points is larger than the error on the proton points is merely due to the fact that less mesons were measured. The fit was compared statistically to the best possible fit to the points and it was found that the predicted line fits the data exactly. Hence it is concluded that the mass dependence is verified.

Although constant cell lengths were used in the treatment of the data, this is not the best way to make use of the information in the track as has been pointed out by several authors [2, 5]. The use of the constant sagitta method is preferable from the standpoint of ease of treatment of the data as well as maximizing the information obtained. The formula (3) can readily be used to compute suitable scattering schemes for various particles. This is being done now and will be published in a longer report on the present investigation. Measurements on negative K-mesons will also be published there.

* * *

I would like to thank Professor M. SCHEIN for his constant advice and encouragement, as well as for the facilities of his laboratory. Thanks are also due to T. BOWEN and D. M. HASKIN for their aid in making the exposure and developing the plates, and to E. WAEHRER for his aid with the computations. Thanks are also due to Professor H. L. ANDERSON and Mr. L. KORNBLITH for the use of the synchrocyclotron.

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Measurements of Microscope Stage Noise.

K. GOTTSTEIN
Max-Planck-Institut für Physik - Göttingen

In many laboratories investigations are now going on which involve the necessity of measuring multiple scattering on very energetic i.e. very straight tracks. I only mention the experiments on the mass and energy spectrum of the particles in jets and of the primary component of the cosmic rays. In these experiments one often has to employ cell sizes $> 500\ \mu$ or even of 1 mm in order to obtain a « signal » significantly greater than the spurious scattering. Now this spurious scattering, or « noise », if measured by the co-ordinate method, consists of one component which is independent of cell-size, and which is due to the finite size of the grains and to errors of judgment by the observer, and to one which increases with increasing cell-length. This latter has to be attributed to mechanical irregularities of the microscope stage transport. (Another source of « noise », also dependent on cell-size, is the distortion of the emulsion, but this will not be discussed in the present lecture). If one knows the laws according to which the noise varies with cell-size, one is in a position to eliminate it to a large extent and to raise the limit to which one is able to make accurate energy measurements.

If one assumes a power law for the dependance of stage noise on cell-size S, (measured in units of $100\ \mu$), the corresponding scattering is given by

$$\bar{D}^2 = \bar{D}^2_{100} S^3 + kS^n \,,$$

where D^2_{100} is the « true » mean square sagitta corresponding to a cell-size of $100\ \mu$. Then the corrected value for the true scattering is given by the well-known formula

$$D^2_{100} = \frac{D_1^2 - D_2^2(S_1/S_2)^n}{S_1^3 - S_2^3(S_1/S_2)^n}\,.$$

In order to get a clear idea about stage noise in general and on what can be done about its diminution, and on the merits of the different types of microscopes in particular (which members of our group at Göttingen were

using, are using, or might be using in the future), we have made a systematic check of the mouvement of the stages of seven different microscopes:

3 Cooke M 4000;
1 Leitz Ortholux;
1 Leitz Koordinaten-komparator;
1 Zeiss Standard;
1 Koristka M. S. 2.

For this purpose we have used a simple interferometric device which Messrs. Zeiss-Winkel (Göttingen), specially designed for us last year and which

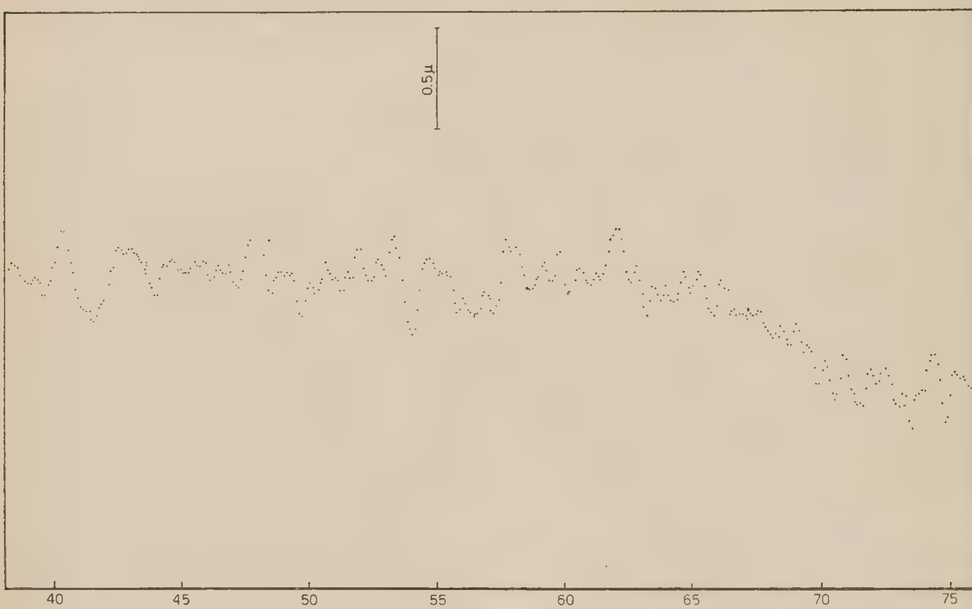

Fig. 1.

allows the simultaneous measurement of « sagittal » and « angular » stage-noise. It consist of a 10 × objective which is screwed into the revolving head of the microscope in a horizontal position. In front of its front lens is mounted a plane, semi-silvered glass plate. The movement of the fringes produced by interference between this plate and a second semi-silvered, plane plate attached to the stage is then observed while the stage is moved slowly from one end of the transporting screw to the other. Readings of the position of the fringes were taken every 50 μ, using one of the eyepiece scales normally employed for reading the co-ordinates of grains in scattering measurements. A sodium lamp was employed as a light source. A lateral displacement of one of the glass plates with respect to the other (i.e. sagittal noise) is then indicated by a lateral displacement of the whole field of fringes, whereas a change in the

angle between the glass plates (i.e. angular noise), makes itself known by a change in the distance between individual fringes.

For small angles the following relations hold:

$$\Delta x = \frac{\lambda}{2\alpha},$$

$$\Delta d = N \cdot \frac{\lambda}{2}.$$

Δx = Distance between fringes (in μ).
α = Angle between semi-silvered surfaces (in radians).
λ = Wave-length of Na light (0.589 μ).
N = Number (or fraction) of fringes passing a fixed line in the field when lateral displacement Δd (in μ) occurs.

On the occasion of my visit to Messrs. Koristka in Milan last week, I found that they have now independently developed an interferometer working on essentially the same principle.

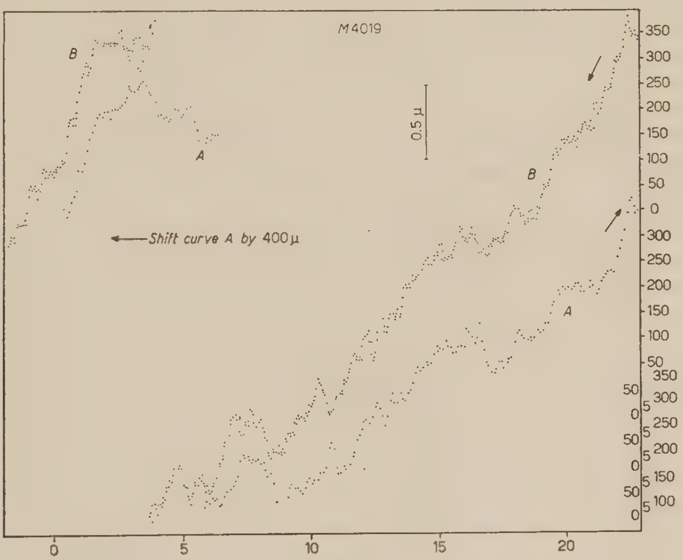

Fig. 2.

Fig. 1 shows one example of our results. The lateral displacements are plotted as a function of screw length. Fig. 2 shows two curves measured on two different days by two different observers and in the opposite directions of motion, and demostrate the good reproducibility of even small peaks of less than 0.1 μ amplitude.

In Fig. 3 are shown the values of the mean second difference due to stage noise, $D_{\text{stage noise}}$, for different cell-sizes. One notices that there are considerable differences in the performance of different instruments, even of those of the same make, and this stresses again the great importance of treating one's scattering microscopes with care and consideration, for some of these differences are probably due to the different treatments which these instruments have experienced during their life. The example of the Koordinatenkomparator (« Nukleo ») also shows that the way of handling the controls of the instrument during the measurement is of influence. The series of measurements which were made without touching the nonius of the reading microscope, show a considerably smaller noise.

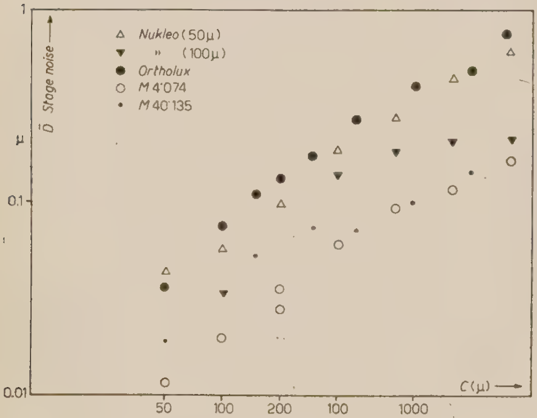

Fig. 3.

In Fig. 4, a constant contribution for « reading » and « grain noise » has been added to the stage noise. The resulting total noise varies with the cell-

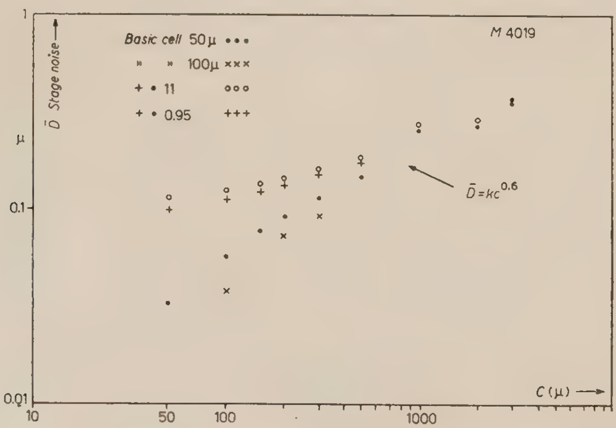

Fig. 4.

size, approximately as $S^{\frac{1}{2}}$, a result in agreement with the one obtained previously by FOWLER on the same microscope.

The « angular » noise was not measured systematically every 50 μ since we

rarely use the angular method now. The distance between the fringes was, however, checked after certain intervals. The angle between the semi-silvered surfaces being of the order of $0^\circ.05$, there was no indication with any of the microscopes used that the changes in this angle were at any time larger than 20%.

I should like to remark that, except in the case of Messrs. Zeiss and Messrs. Koristka, the investigations mentioned were carried out without the knowledge of the firms which manufactured the microscopes. The results on stage noise presented might, therefore, not be fully representative of what the firms concerned could have achieved, had they been called upon to put forward their very best products for this purpose.

A Thorough Investigation of the Accuracy of Photoelectric Mass Determinations.

K. KRISTIANSSON

Department of Physics of the University - Lund

The accuracy with which a determination of the mass of a particle stopping in the emulsion can be made by measurements of the number of grains in the track is given by the quality of the emulsion and by the accuracy with which the grain density of the track can be measured. The determination of the grain density can be made by photo-electric measurements of the mean width of the track. A photo-electric measurement of the mean track width is, in principle, more complicated than grain counting and gap measurements. Therefore it is important to investigate the reliability of the method and the accuracy of such measurements, in order to find out if the extra work is justified.

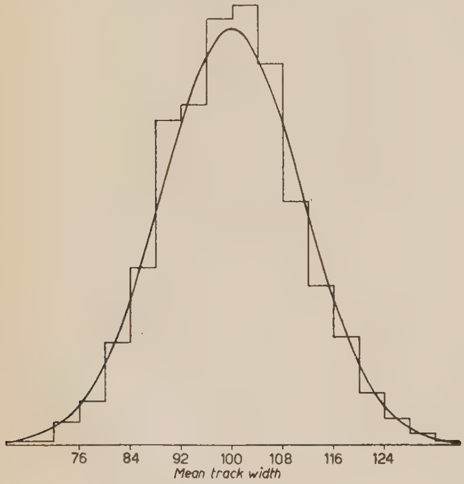

Fig. 1.

Such an investigation of the photoelectric method has been made on tracks in a G-5 emulsion exposed in a balloon flight of the Sardinian expedition 1952 (*). The measurements have been carried out with the apparatus built at Lund on tracks of singly charged particles. All measure-

(*) *Arkiv för Fysik* (in print).

ments have been made with a slit with the dimensions $2.4 \times 30\ \mu$ measured in the objective plane. They have been corrected for uneven development.

The distribution of the measurements in the proton tracks is shown in Fig. 1. The variation of the ionisation in measurements at different residual ranges has been compensated for. The figure shows that the distribution of the measurements is a Gaussian one. The standard deviation amounts to 11%.

The masses of the particles which have been measured have been

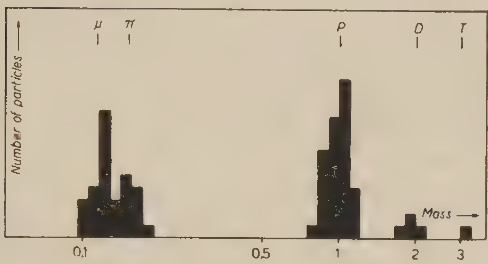

Fig. 2.

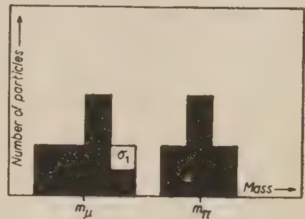

Fig. 3.

calculated by a method of least squares. The histogram in Fig. 2 gives the distribution of the masses. The residual ranges of the μ-mesons have been 700 μ, of the π-mesons 1000 μ and of the heavier particles at least 3 000 μ. This histogram gives an answer to two questions: 1) Does there exist any systematic error in a mass determination by photo-electric measurements? 2) Which accuracy can be expected in a mass determination?

The position of the different groups of particles in the histogram can be compared with the correct positions which are indicated by arrows. The correspondance is very good, which means that there is no reason to believe that the photo-electric method of determining masses suffers from any systematic errors. The correspondence can be illustrated by an example. The mean value of the masses of the 19 μ-mesons has been calculated to $213 \pm 6\ m_e$ for a proton mass of 1836 m_e which agrees well with the correct mass of the μ-meson.

The separation between π- and μ-mesons is not complete depending upon the too short residual ranges of the tracks used. A determination of the meson masses on tracks with a residual range of about 1 400 μ is shown in Fig. 3. From the distribution of particles in this diagram it can be computed that the probability of false identification of the mesons is less than 2% if the residual range is 1 400 μ or more. The σ-meson in the μ-meson group gives a star with only one very short track, a proton track. On that account it seems not to be improbable that the σ-meson is a negative μ-meson.

The accuracy with which a mass determination can be made, can be determined from the distributions of the mass values in the different groups of particles in Fig. 2. The standard deviation in the proton group has been calculated to 10% and it is approximately the same in the groups of π- and μ-mesons. This result shows that the standard error in a determination of the mass of an unknown particle is approximately 10% if the residual range of this particle is comparable to the ranges of the particles in the histogram. That means that the mass of a K-particle with a residual range of about 3 000 μ can be measured with a standard error of 10%, if the tracks for the comparison are chosen at random in the plate.

Another problem, which has been studied is how this standard error of the mass determinations varies with the residual range of the particle. By a statistical analysis of the measurements it has been possible to split up the errors into three components depending on, 1) errors from the experimental technique, 2) statistical distribution in the number of grains in the track, 3) irregularities in the emulsion. By a knowledge of those three components and how they vary with range it has been possible to compute the total error in a mass determination for particles of different masses and different residual ranges. The diagram in Fig. 4 shows the result of such a calculation for protons and π- and μ-mesons. The calculated standard errors can be compared with the standard errors in the direct measurements of proton and meson masses, which also can be seen in the diagram.

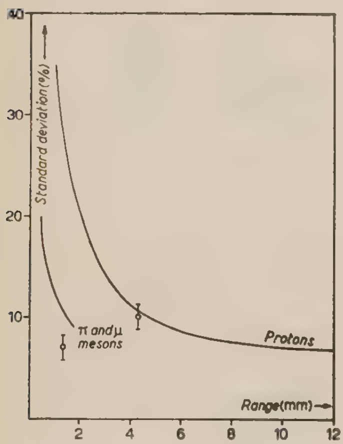

Fig. 4.

For short ranges the errors in the experimental technique and the statistical variation in the number of grains dominate. But these errors will be reduced comparatively rapidly when the range increases and the errors from irregularities in the emulsion will then become important. These irregu'arities appear as regions in the emulsion with different average value of the mean track width. The variation of this average value amounted to about 2% in the plate in which the tracks were measured. The diameter of regions with approximately constant value of the mean track width is of the order of a few centimeters. Whether the irregularities depend on the development, on variations in sensitivity or on different mean diameters of the grains in different parts of a plate can't be determined from the measurements. von Friesen (*) has shown that the irregularities can be detected by measurements on the back-

(*) *Arkiv för Fysik* (in print).

ground and that by means of the results of such measurements a correction can be applied to the mass values which reduces the errors considerably.

The regions with approximately the same average value of the mean track width are large. Therefore the tracks for the comparison in a mass determination will as a rule lie in the same region as the track of the unknown particle if they are chosen as close to this particle as possible. If this condition is fulfilled the error in a mass determination will be reduced appreciably. The mass of a K-particle with a residual range of 3 000 μ can be determined with an error not exceeding 6-7 % if the degree of development gives good resolving power to the emulsion.

Méthodes de mesures de masses par scattering, comptage de lacunes, et comptage de grains, utilisées par le Groupe de l'École Polytechnique (Paris).

A. ORKIN-LECOURTOIS, G. KAYAS et HOANG-TCHANG-FONG

Présentées par L. JAUNEAU.

Laboratoire de Physique de l'École Polytechnique - Paris

Une méthode servant à déterminer la masse des particules dont la trace se termine dans l'émulsion utilise la mesure du scattering en fonction du parcours, les cellules étant choisies de manière à maintenir la flèche constante. Elle est appliquée par M.lle ORKIN-LECOURTOIS.

Soit $\bar{\alpha}$ l'angle moyen de scattering rapporté à la cellule unité:

$$\bar{\alpha} = \frac{K}{p\beta c}(R) .$$

L'énergie, et donc $p\beta c$, varie en fonction du parcours. On utilise la relation parcours-énergie donnée par VIGNERON:

$$E = CR^a M^{1-a} \qquad \text{avec } C = 1,46 \cdot 10^{-3}, \quad a = 0,568$$

la masse étant exprimée en MeV. On obtient:

$$\bar{\alpha} = \frac{K}{c} M^{a-1} R^{-a} f_M(R) ,$$

avec

$$f_M(R) = \frac{1 + C(R/M)^a}{2 + C(R/M)^a} ,$$

fonction égale a $\frac{1}{2}$ pour des vitesses non relativistes.

La flèche mesurée sur une cellule égale à s est telle que:

$$\bar{\delta}^2 = \bar{\alpha}^2 s^3 .$$

On choisit $s(R)$ de manière à maintenir δ constante et égale à δ_0 sur tout le parcours

$$s^3 = \delta_0^2 \frac{1}{\alpha^2} = \delta_0^2 \left(\frac{C}{K}\right)^2 (M_0^{1-a})^2 R^{2a} f_{M_0}^{-2}(R) = b^2 R^{2a} f_{M_0}^{-2}(R) .$$

Ceci donne le schéma de cellule pour une masse M_0, $f_{M_0}(R)$ agissant comme une fonction de correction aux vitesses relativistes.

Si la mesure est effectuée sur une particule de masse M:

$$\bar{\delta}^2(R) = \bar{\alpha}^2 s^3 = b^2 \left[\frac{K}{C} M^{a-1}\right]^2 f_{M_0}^{-2}(R) f_M^{+2}(R)$$

$$f_{M_0}^{-1} f_M \neq 1 \qquad \text{pour} \qquad \frac{M_0}{2} < M < 2M_0 ,$$

δ ne dépend plus de R que par l'intermédiaire de la constante K. On peut donc écrire

$$\bar{\delta} = \frac{b}{C} \bar{K} M^{a-1} \qquad \text{avec} \qquad \bar{K} = \frac{\sum n_i K_i(s_i)}{\sum n_i} , \quad (*)$$

les (n_i, s_i) constituant le schéma utilisé

$$\text{ou} \qquad \frac{\bar{\delta}}{\bar{K}} = \frac{b}{C} M^{a-1} \qquad \text{avec} \qquad b = \delta_0 \frac{C}{K} M_0^{1-a} .$$

La grandeur b arbitraire régit la hauteur du schéma adopté. On a construit trois schémas distincts avec b proportionnel à M_0^{1-a}, de manière à garder δ_0 constant d'un schéma à l'autre. Pour se placer dans les conditions optimum pour l'élimination du bruit de fond, on a pris $\delta_0^2 = \varepsilon^2$, bruit de fond. On commence les mesures à 200 μ environ.

On a donc théoriquement pour ces schémas avec l'optique choisie

$$\left(\frac{\bar{\delta}}{\bar{K}}\right)_{\text{proton}} = \left(\frac{\bar{\delta}}{\bar{K}}\right)_{\pi} = \left(\frac{\bar{\delta}}{\bar{K}}\right)_{\text{masse quelconque}} = 424 \cdot 10^{-4} .$$

La mesure de $\bar{\delta}/\bar{K}$ pour 19 protons et 18 π (dont 5 d'inclinaison supérieure

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(*) Les coupures sont effectuées à $4\bar{\delta}$ et K_i (s_i, R_i, M_0) est calculé à l'aide des courbes de Pickup et Voyvodic parues dans *Phys. Rev.*, **85**, 91 (1952).

à 50%) a fourni

$$\left(\frac{\bar{\delta}}{K}\right)_{\text{exp}} = (426 \pm 6) \cdot 10^{-4}\,.$$

On peut donc écrire:

$$\left(\frac{\bar{\delta}}{K}\right)_{M} = 426 \cdot 10^{-4} \left(\frac{M}{M_0}\right)^{1-a}.$$

d'où M.

Les mesures sont effectuées sur un microscope Leitz Ortholux. Le déplacement le long de la trace selon le schéma choisi est repéré avec un oculaire à fil mobile. Une montre micrométrique contrôle en même temps le déplacement de la platine. Le bruit de fond est éliminé entre la cellule de mesure et la cellule double.

L'erreur statistique est donnée théoriquement par $\Delta M/M = 2{,}9/\sqrt{n}$ (soit 13 à 14% sur 1 cm sur une masse 1000). Les particules d'étalonnage ayant montré une dispersion un peu plus grande (l'écart-type sur la flèche est de 10% au lieu de 8% prévu par la théorie), la formule d'erreur a été corrigée en conséquence:

$$\frac{\Delta M}{M} = \frac{3{,}6}{\sqrt{n}}\,.$$

Les traces inclinées subissent une correction. Pour $\Delta R/R = \Delta s/s$, la correction est $\ln(\cos\theta_{\text{corr}})^{2,3}$ sur la masse M.

La flèche correspondant à la déformation de l'émulsion a été déduite de la moyenne algébrique des différences secondes. Ces corrections se sont élevées au plus à 4 ou 5% sur le $\bar{\delta}$ de certaines plaques dont le vecteur de distortion atteignait 50 μ.

Cependant, on observe une variation de $\bar{\delta}/\bar{K}$ avec le parcours total utilisé pour la mesure, comme l'indique le Tableau I où R_1, R_2, R_3 correspondent à 150, 300 et 600 mesures respectivement.

TABLEAU I.

	R_1 (μ)	R_2 (μ)	R_3 (μ)
p	2 500	6 500	18 500
π	1 400	3 200	8 500
$10^4 \cdot \bar{\delta}/\bar{K}$	395 ± 10	426 ± 7,2	440 ± 7,4

Cet effet peut provenir, soit d'une saturation du scattering vers la fin du parcours (le nombre de collisions par cellules devient faible, de l'ordre de 10

à 50), soit de la loi de variation de la cellule. La dispersion observée aux différents parcours ne présente pas de variation systématique.

On a tracé l'histogramme de $10^4 \cdot \bar{\delta}/\bar{K}$ pour les particules d'étalonnage (Fig. 1) et pour les 16 mésons K mesurés dans 59 plaques, ces derniers avec le schéma $M_0 = 1000\ m_e$ (Fig. 2). Toutes ces mesures ont comporté environ 300 pointés, au moins.

La valeur moyenne pondérée de la masse des 12 mésons K est $1037 \pm 60\ m_e$. La valeur moyenne des 2 mésons τ est $955 \pm 130\ m_e$.

Dans le Tableau II, les traces des particules marquées d'un astérisque présentent une inclinaison corrigée supérieure à 3%.

Tableau II.

Particule	Parcours utilisé (μ)	No. plaques	No. mesures	$10^4 \cdot \bar{\delta}/\bar{K}$	M (m_e)	$\pm \Delta M$	$\Delta M/M$ (%)
K-Ep_8	9 500	2	447	442	920	157	17,0
K-Ep_9^*	1 870	2	123	392	1 210	390	32,5
K-Ep_{10}	8 900	3	400	408	1 100	198	18,1
K-Ep_{11}^*	2 800	2	174	411	1 083	294	27,2
K-Ep_{12}^*	6 600	5	270	469	805	177	22,0
K-Ep_{13}^*	5 300	3	260	366	1 415	316	22,3
K-Ep_{15}^*	2 040	2	130	425	1 005	320	31,8
K-Ep_{16}	9 800	4	415	412	1 075	190	17,7
K-Ep_{18}^*	6 700	7	270	394	1 195	263	22,0
K-Ep_{21}	17 700	4	630	405	1 120	161	14,4
K-Ep_{22}^*	9 400	7	340	387	1 230	240	19,5
K-Ep_{25}	5 000	5	270	510	655	145	21,9
K-Ep_{14}	9 700	3	420	439	934	165	17,7
τ-Ep_1^*	6 700	4	270	443	913	200	21,9
τ-Ep_2	10 300	5	430	430	980	170	17,3
τ'-Ep_1	6 700	3	324	375	1 350	270	20,0

Une autre méthode de détermination des masses des particules en fin de parcours, étudiée et appliquée par G. KAYAS [1], utilise la mesure des lacunes.

Dans cette méthode, on compte toutes les lacunes, sans coupure. Dans le cas des émulsions sans support, la densité de lacunes au passage d'une plaque à la suivante est

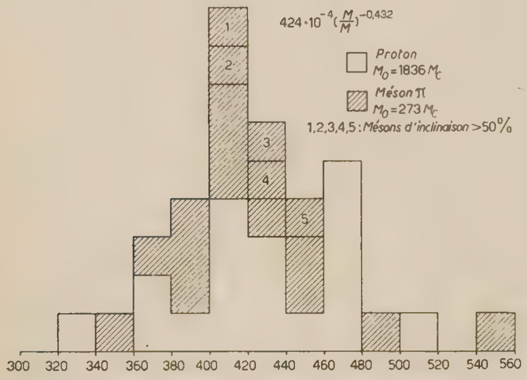

Fig. 1.

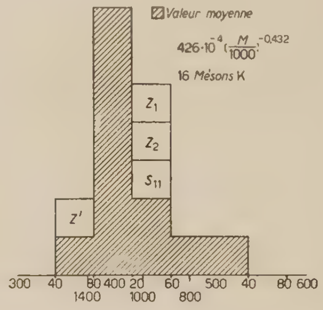

Fig. 2.

prise égale à la moyenne des densités mesurées sur les portions immédiatement voisines. L'expérience montre alors que la variation du nombre intégral G des lacunes, comptées à partir de la fin de la trace, en fonction du parcours R, est représentée avec une très bonne approximation par une loi de puissance (pour le proton)

$$G = aR^n .$$

Pour des protons, cette relation est valable jusqu'à des parcours de l'ordre de 20 000 μ.

L'exposant n varie peu pour des traces prises sur des émulsions ayant subi des développements différents. Au contraire, le coefficient a dépend du développement de l'émulsion (Tableau III).

TABLEAU III. – *Valeur de n et a en fonction du développement dans les plaques Ilford G5.*

	min. d'ionisat.	n	a
Série Sardaigne	16	1,155	0,122
» Harwell	?	1,238	0,045
» 105	30	1,316	0,018

Dans le cas des émulsions utilisées pour la recherche des méson lourds, la loi expérimentale a été déterminée par l'étude de 10 protons et 7 mésons π.

La détermination de la masse M d'une particule se fait par comparaison, en coordonnées bilogarithmiques, entre la droite correspondant à cette particule et la droite correspondant aux protons d'étalonnage. Si l'on coupe la droite du proton, par une droite inclinée à 45°, au point correspondant au parcours 1840, l'intersection de cette droite avec celle de la particule mesurée donne la masse M. Si la droite correspondant à la masse M a été encadrée par deux droites distantes chacune d'un écart-type, on obtient ainsi une estimation de l'erreur commise sur M (Fig. 3).

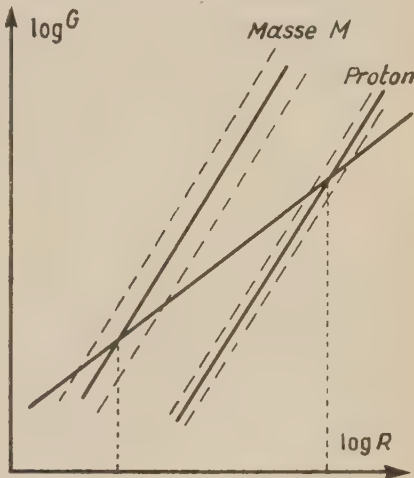

Fig. 3.

L'ordre de grandeur des erreurs est: 10% si $G > 2\,000$.

Une troisième méthode, étudiée par HOANG-TCHANG-FONG [2], utilise la variation de la densité de grains en fonction du parcours. Elle a été étalonnée à l'aide de 20 mésons π ayant chacun un parcours restant de plus de 2 cm et une inclinaison inférieure à 20%. Le comptage de grains a été effectué sur chaque trace à des parcours déterminés (3130 μ, 5350 μ, 10100 μ, 15000 μ, 20000 μ, 30000 μ, 40000 μ, 50000 μ) avec des cellules de comptage inégales ($R - \Delta R_1$, $R + \Delta R_2$) telles qu'il y ait autant de grains dans ΔR_1 que dans ΔR_2 et que le nombre total de grains comptés soit suffisamment grand ($>1\,000$) afin que les fluctuations sur la densité de grains g ainsi mesurée ne dépassent pas 3%.

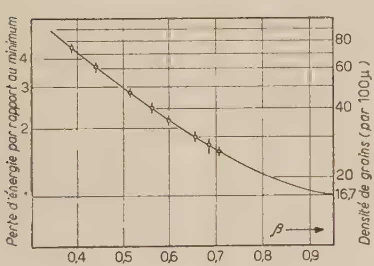

Fig. 4.

Les résultats des mesures montrent que les différentes valeurs de g se groupent autour d'une courbe moyenne avec une dispersion de l'ordre de 6% (Fig. 4). On peut déduire la perte d'énergie $\mathrm{d}E/\mathrm{d}R$ de la relation parcours-énergie

$$\frac{E}{M} = 1{,}46\cdot 10^{-2}\left(\frac{R}{M}\right)^{0{,}568}.$$

Pour β compris entre 0,39 et 0,71 il y a proportionnalité entre la densité de grains et la perte d'énergie:

$$g = \lambda\frac{\mathrm{d}E}{\mathrm{d}R} + \mu\,,$$

avec

$$\lambda = 12{,}90 \pm 0{,}02 \qquad \mu = 3{,}44 \pm 0{,}16\,.$$

Il y a accord entre la courbe expérimentale $g = f(\beta)$ et la courbe théorique de Bethe-Bloch donnant $\mathrm{d}E/\mathrm{d}R$ dans le cas de AgBr pour une valeur du minimum d'ionisation égale à 16,7 grains/100 μ. L'ionisation correspondant au plateau, déterminée au moyen des traces de particules très énergiques, est de 18,5 grains/100 μ.

On peut estimer la masse d'une particule en comparant la variation de la densité de grains de sa trace en fonction du parcours R avec la variation $g(R)$ obtenue pour les π d'étalonnage. Si l'on fait l'hypothèse que les fluctuations de la densité de grains sont gaussiennes, on peut appliquer la méthode du maximum de vraisemblance à un paramètre, M.

La masse moyenne des 20 π d'étalonnage, déduite de cette méthode, est :

$$M = (276{,}5 \pm 16{,}5)\ \mathrm{m}_e ,$$

16,5 étant l'écart quadratique moyen des valeurs de M par rapport à la moyenne. Il est du même ordre que l'écart-type déduit de la méthode de maximum de vraisemblance. La dispersion de l'étalonnage est donc d'environ 6 %.

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SUPPLEMENTO AL VOLUME XII, SERIE IX DEL NUOVO CIMENTO - N. 2, 1954

Mesures de masses dans les plaques photographiques au moyen de mesures photométriques de l'ionisation.

C. MABBOUX et D. MORELLET
Laboratoire de Physique de l'École Polytechnique - Paris

La mesure photométrique de l'ionisation d'une trace de particule en fonction de son parcours restant fournit un moyen de déterminer sa masse. Le développement récent de cette tecnhique de mesure est justifié par les caractères propres de la photométrie à savoir son objectivité, sa simplicité, sa rapidité, sa fidelité et surtout sa grande sensibilité dans un domaine d'ionisation accessible pour la plupart des traces s'arrêtant.

Cette méthode purement expérimentale ne suppose aucune loi explicite entre l'énergie cinétique, le parcours restant et la perte d'énergie par ionisation. Elle permet l'utilisation directe des résultats de mesure à partir d'une hypothèse élémentaire sur la relation qui lie le parcours restant à la perte d'énergie par ionisation. En outre les traitements ordinaires de combinaison statistique permettent d'en définir aisément les limites d'erreurs.

Nous traiterons ici du cas particulier d'un assez long parcours restant; en effet l'utilisation généralisée des émulsions sans support permet de réaliser de telles conditions de mesure. Nous nous restreindrons aussi aux problèmes posés par la particules de masse voisine de 1000 m_e, celle-ci étant en ce jour de grande importance.

Appareil de mésure photométrique.

L'appareil utilisé est une version améliorée de celui que nous avons décrit antérieurement. Il est basé sur le même principe, de ne déplacer que l'image de la fente dans le plan de l'émulsion.

Un balayage perpendiculaire à la trace est réalisé au moyen d'un prisme de verre de section carrée, d'arête parallele à la fente, tournant uniformément

à raison de 1500 tours/min autour de son grand axe, celui-ci étant dans le plan vertical contenant la fente.

Deux faces opposées de ce prisme sont noircies, de sorte que le faisceau soit périodiquement obturé. Dans ces conditions, en l'absence de tout trace, l'oscilloscope placé à la sortie du photomultiplicateur reçoit un train d'impulsions carrées correspondant aux suites lumière - obscurité - lumière..., etc. Si l'on introduit la trace dans la région balayée, son profil de noirceur se superpose à la partie « lumière » du signal carré. Au cours des mesures la hauteur H du signal carré est maintenue strictement constante par action sur la tension d'alimentation du photomultiplicateur.

Nous avons signalé autrefois que pour ce type de photomètre utilisant une fente image très fine (0,15 μ), le réglage du parallélisme entre la fente et la trace doit être aussi parfait et souple que possible. A cet effet, nous avons introduit entre le prisme de balayage et l'oculaire un prisme de Wollaston d'axe vertical. Quand ce prisme tourne de l'angle 1 autour de son axe, la fente image tourne alors de 2 autour de l'axe optique. L'entraînement de Wollaston peut-être exécuté avec grand soin.

Le microscope utilisé est un Leitz Ortholux à vision monobinoculaire. La fente est réglable de manière précise en longueur et en largeur.

Principe de mesure.

A chaque pointé, H est normalisée à une valeur H_0 constante afin d'éliminer la plus grande partie du « bruit de fond » (variations locales de transparence, proximité d'autres traces..., etc.). La grandeur mesurée est alors la hauteur h du profil de noircissement. Cette hauteur est obtenue à vue sur l'oscilloscope par maximum en agissant sur l'orientation de la fente et la vis micrométrique de mise au point.

Cette valeur directe de h est soumise à deux corrections standard. L'une (correction de profondeur) qui tient compte de la profondeur P du point de mesure au sein de l'émulsion est un fonction linéaire de P. L'autre (correction de pente) qui tient compte de l'inclinaison θ de la trace au point de mesure est égale à tg θ pour tg $\theta < 10\%$.

Méthode d'estimation d'une masse.

L'hypothèse du départ est celle-ci: à même β, deux particules ont même ionisation et leurs respectifs parcours restants sont alors liés aux masses correspondantes par

$$R_1/R_2 = M_1/M_2 = k \,,$$

ce qui dans le langage de notre méthode s'exprime ainsi: $k = M_1/M_2$ est égal au rapport des parcours respectifs pris en des points de même valeur de h.

Il en découle immédiatement qu'à chaque mesure h d'une particule M_2 on peut associer une valeur de k pourvu que l'on dispose d'une particule de référence (expérimentale) M_1 (Fig. 1). On peut combiner statistiquement les valeurs de k correspondant à chaque mesure opérée sur la particule inconnue. Un traitement statistique rigoureux conduit à la meilleure estimation $\hat{k}$ de k, déduite de N mesures, et à la variance qui lui est liée:

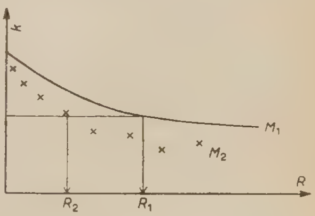

Fig. 1.

$$\hat{k} = \frac{\sum R_1 R_2}{\sum R_2^2},$$

(R_1, R_2 correspondant au même h) et

$$\sigma^2_{\hat{k}} = \frac{1}{N}\left[\frac{\sum R_1^2}{\sum R_2^2} - \hat{k}^2\right].$$

La courbe de référence M_1 est obtenue par une moyenne sur des particules connues de même espèce (protons).

Test de sensibilité sur 35 Protons.

Les plaques pelées utilisées présentent 18 grains/100 μ au minimum d'ionisation et ont tous les caractères de qualité requis par notre méthode (uniformité, clarté, développement peu poussé). La correction de profondeur maxima (290 μ) correspondante est de $0{,}25 \cdot h$.

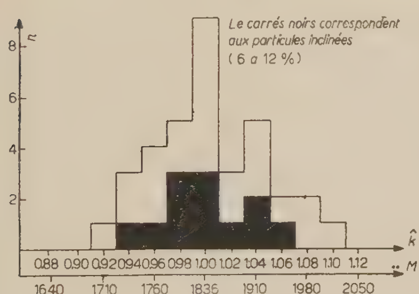

Fig. 2.

Nous avons systématiquement étudié 35 protons afin de déterminer la précision de la méthode ainsi que la validité des corrections employées. Ces particules présentent des parcours de 7 500 à 10 000 μ. Le schéme da mesure est le suivant: jusqu'à 5 000 μ, tous les 50 μ; à partir de 5 000 μ, tous les 100 μ; soit au total 150 mesures pour 10 000 μ de parcours.

En comparant chaque proton à la courbe moyenne totale, on obtient 35 valeurs de masse réparties selon une loi de distribution d'écart-type bien défini, σ^2_{mes}. Les résultats sont reproduits dans la Fig. 2.

L'écart-type associé à cette distribution est de 110 m_e, soit $\Delta M/M = 6\%$. Les protons considérés présentent des pentes comprises entre 0 et 11% et sont distribués dans toute l'épaisseur de l'émulsion.

Estimation d'une masse voisine de 1 000 m_e.

a) *Schéma de mesure.* – Pour de telles particules on a $M_1/M_2 \simeq 2$; par suite pour chaque valeur de h on a $R_1/R_2 \simeq 2$. Le parcours de comparaison de la particule 2 à la particule 1 (proton) sera de 5 000 μ seulemont.

Afin d'obtenir sur ce parcours la même information statistique que celle fournie par la particule de référence nous faisons des mesures 2 fois plus serrées, ce qui est possible puisque la fente image ne mesure que 23 μ de long.

b) *Erreurs sur l'estimation de la masse.* – Ces erreurs sont de 3 types distinctes.

1) Des erreurs de mesures (précision de la méthode): on peut considérer que, les mesures étant effectuées dans des conditions très semblables, on a $\Delta M_1/M_1 = \Delta M_2/M_2$. Ceci n'est toutefois pas exactement juste très près de la fin de parcours, car les effets de scattering ne sont pas tout à fait de même grandeur. Il est bon de faire une coupure aux faibles parcours (de l'ordre de 750 μ pour un méson 1000).

2) Une erreur du fait que la particule de référence n'est pas parfaitement déterminée mais seulement estimée au moyen d'un nombre fini de protons. La distribution de N protons nous fournit la variance sur la moyenne, soit σ^2_{ref}

$$\sigma^2_{ref} = \sigma^2_{mes}/n\,, \qquad n = \text{nombre de particules utilisées.}$$

3) Une erreur statistique du fait que la population choisie pour l'estimation de la masse ne contient que 150 individus. On a vu que cette variance est

$$\sigma^2_{\hat{k}} = \frac{1}{\mathrm{N}}\left[\frac{\sum R_1^2}{\sum R_2^2} - \hat{k}^2\right].$$

Le calcul rigoureux de combinaison de ces erreurs conduit à l'addition simple des 2 premières variances. La troisième variance étant beacuoup plus petite que les deux autres peut-être négligée en première approximation. On a donc

$$\sigma^2_{total} = \sigma^2_{mes} + \sigma^2_{ref}\,.$$

Habituellement, on utilise environ 10 protons de référence choisis pour des raisons de prudence dans le voisinage de la trace à mesurer.

Ainsi une trace de 5 000 μ correspondant à une particule de masse voisine de 1000 m_e permet une estimation de la masse à 7% près (un écart-type). Cette précision a été contrôlée sur plusieurs mésons dont la masse est bien connue.

La méthode photométrique correctement appliquée à des traces de parcours moyen permet donc des estimations de masse entachées d'erreurs relativement petites.

Contribution à l'étude du développement et de la corrosion dans les émulsions nucléaires.

G. MEULEMANS

Laboratoire de Physique Nucléaire de l'Université Libre de Bruxelles

1. – L'opacité due à la coloration des plaques nucléaires développées à l'amidol est bien connue. Même des plaques préalablement fixées et lavées, immergées dans un bain contenant de l'amidol acquièrent cette opacité. Elle semble ainsi due en grande partie à l'adsorption par la gélatine des produits d'oxydation de l'amidol. Nous avons cherché à la réduire en diminuant la concentration d'amidol dans le révélateur.

Trois révélateurs ont été étudiés, dans lesquels — toutes autres conditions égales — nous avons ramené la concentration d'amidol de 4,5 g/litre (concentration moyenne donnée par les manuels de photographie) à 1 g puis à 0,5 g/litre.

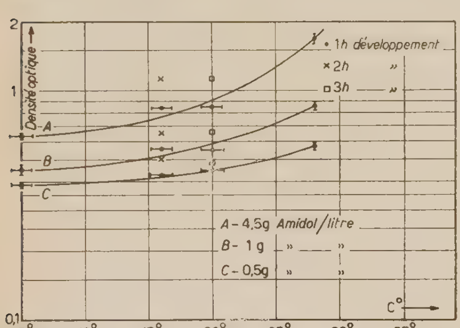

Fig. 1. Émulsion G-5 400 μ d'épaisseur.

Nous avons mesuré la densité optique ainsi que le nombre de grains au minimum d'ionisation de plaques développées dans ces trois révélateurs; la durée de développement variant de 1 à 3 h et la température du stade chaud de 27 à 15 °C.

Les résultats obtenus sont résumés par les graphiques presentés dans les Fig. 1 et 2. Le premier de ces graphiques a rapport à la densité optique mesurée en lumière blanche parallèle et en éliminant la densité optique du verre de support de l'émulsion. Le second montre comment varie le nombre de grains au minimum, en fonction de la température et de la concentration d'amidol. Ce dernier graphique indique qu'il est encore possible d'obtenir des traces au minimum discernables en utilisant eune concentration d'amidol de 0,5 g/litre.

Pour les expérierces d'expositions au rayonnement cosmique — dans les-

quelles le nombre de grains impressionnés n'est pas très élevé — une réduction de la concentration d'amidol de 4,5 g/litre à 1 g/litre bien qu'affaiblissant les traces, donne encore des traces au minimum suffisamment denses pour permettre des mesures confortables. Cet affaiblissement des traces au minimum nous semble largement compensé par le gain appréciable de transparence de la plaque.

Nos mesures montrent que le nombre de grains au minimum n'augmente pas de façon sensible en prolongeant la durée du développement tandis que la densité optique augmente un peu. Le nombre de grains au minimum varie sensiblement en fonction de la concentration en amidol; il est beaucoup moins sensible au changement de température de développement.

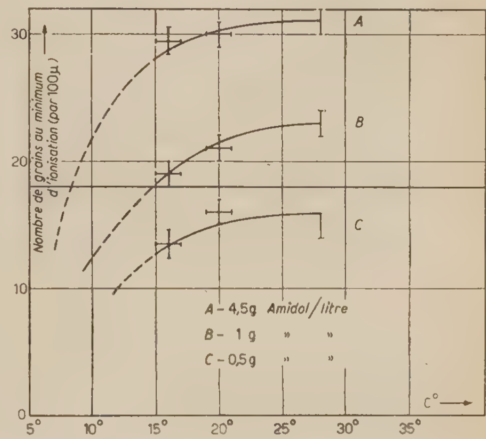

Fig. 2. - Emulsion G-5 400 μ d'épaisseur.

Nous n'avons pas encore étudié en détail l'effet de la concentration en amidol sur la discrimination des particules en fin de parcours. Nous nous proposons de le faire dans un futur proche.

2. – Au Congrès de Bagnères-de-Bigorre, nous avons communiqué (*) des résultats relatifs à l'ampleur de la corrosion produite par les bains de fixage au thiosulfate de sodium, à différents pH et en fonction de la concentration de bromure d'argent dissout dans la solution.

Nous profitons de la présente occasion pour rectifier quelques erreurs qui se sont glissées dans le texte polycopié de cette conférence. Nous confirmons que la présence de sels d'argent dans la solution de fixage protège toujours de la corrosion. Cet effet est très prononcé pour des concentrations en argent de 10 à 20 g/litre, le bain de fixage contenant de 20 à 40 g de bisulfite de sodium par litre (pH de 5 à 4,5). Pour des teneurs supérieures à 40 g de bisulfite de sodium par litre la gélatine s'altère. Pour des concentrations de bisulfite inférieures à 20 g/litre, la protection n'est pas toujours suffisante. Il est cependant encore difficile de donner les conditions optima de fixage car, si l'on observe une sensible amélioration de la transparence dans les plaques fixées en présence de bisulfite de sodium, la turbidité de ces plaques est accrue ce qui rend les mesures malaisées. Ces problèmes seront traités en détail dans une publication ultérieure.

(*) H. Braun, G. Cornil et G. Meulemans: *C. R. Congrès de Bagnères*, 1953, pag. 61.

The Effect of Processing on the Estimation of Ionization by Blob-Counting.

C. O'CEALLAIGH

School of Cosmic Physics, Dublin Institute for Advanced Studies - Dublin

In photographic plate work the fundamental parameter used to estimate the ionization and velocity of a charged particle is the grain-density (g), which may be defined as the number, per unit path, of crystals of silver halide rendered developable by the passage of a charged particle through the emulsion.

Due, however, to the effects of physical development and imperfect optical resolution, it is impossible to observe all the individual grains. Because of this, it has been the custom to allow for the grains lost to observation by the application of conventions based on the lengths of the clogged portions of the tracks. This method is both subjective and tedious. It has now been displaced by the technique of blob-counting in which each segment of the track bounded by detectable gaps is counted as one blob whether the blob be composed of one grain or many. The purpose of this note is to draw attention to certain features of blob-counting of interest in practice, and to indicate how these depend on the degree of development and fixing of the plates.

As has been shown elsewhere [1, 2], the following relationships subsist between parameters associated with the developable crystals

$$(1) \qquad 1/g - \alpha = \overline{G}\,, \qquad G = 1 - \alpha g\,,$$

where g = grain density defined as above,

$\overline{G}$ = mean gap-width,

G = gap-density,

α = mean crystal diameter assumed spherical.

During processing, the crystals of silver halide are developed into grains of silver the mean diameter of which, a, is generally different from α, that of

crystals from which they have been formed. In average circumstances the value $a/\alpha \sim 2$. Because of these changes, it might be expected that the gap-length distribution between grains differs from that between the crystals from which they have been developed. Experimentally [1, 2], it may be shown that the distribution of gap-widths Z between grains is indistinguishable from the truncated exponential law

$$P(Z) = F/\overline{G} \exp[-Z/\overline{G}] . \tag{2}$$

It is plausible to suppose that the distribution of gaps, say x, between developable crystals is also exponential

$$P(x) = 1/\overline{G} \exp[-x/\overline{G}] . \tag{3}$$

Assuming (3), we may allow for changes in crystal diameter during processing by means of a simple model. Subject to certain minor restrictions, we obtain the distribution (2) in which

$$F = \exp[-(a - \alpha + \varepsilon_0)/\overline{G}] , \tag{4}$$

where ε_0 is the minimum resolvable gap-width. F is a loss-factor and gives the fraction of the gaps between developable grains which are lost through fusion because of physical development and eclipse arising from failure of optical resolution.

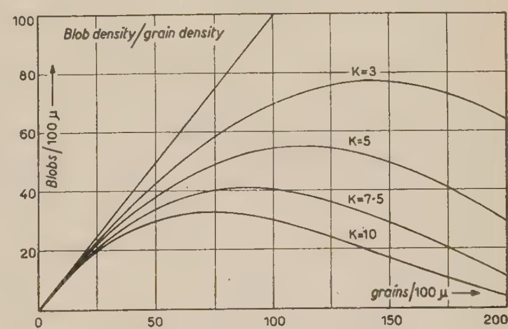

Fig. 1.

We may show from (2) that the distribution $P(Z)$ has the same mean value $\overline{G}$ as $P(x)$. It follows that the measured value of $\overline{G}$ is sensibly independent of the degree of physical development.

Again, within the limits of validity of the assumptions, the relationship between blob-density (b) and grain-density (g) is given by the expression

$$b = g \exp[-(a - \alpha + \varepsilon_0)/\overline{G}] = g \exp[-K/\overline{G}] . \tag{5}$$

Curves showing the relationship between g, b and $\overline{G}$ for selected values of the parameter K, are shown in Figs. 1 and 2. These have been drawn for G5 emulsions using the manufacturer's value of $\alpha = 0.27\ \mu$.

Fig. 1 shows b as a function of g and Fig. 2 shows the corresponding curves for b as a function of $\overline{G}$, for the values $K = 3$, $K = 5$, $K = 7.5$ and $K = 10$.

expressed in eyepiece micrometer drum divisions, 11.2 divisions = 1 μ. The parameter K is clearly a function of a/α which is a measure of the degree of physical development, and also of ε_0 which depends on the resolving power of the optical system. The value $K=3$ corresponds to a very slight degree of physical development, and $K=10$ to what would be regarded as an overdeveloped plate. All these curves pass through a flat maximum. Experiments in progress show that the relationship between b and $\overline{G}$ may be fitted by curves of the form shown in Fig. 2.

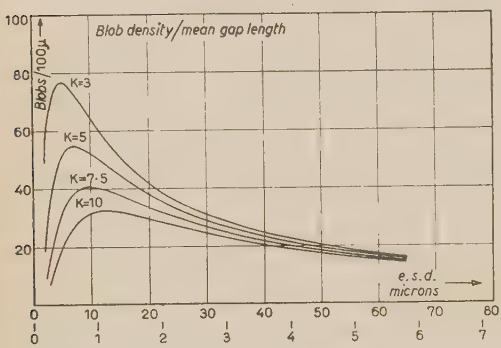

Fig. 2.

It is clear that observations of b made in the region of this maximum are valueless as a means of estimating ionization.

Most important in practice, however is the characteristic curve, blob-density residual range. These are shown (Fig. 3) for protons in two plates of different character, as a function of the values K already selected. One plate, (hatched lines) was normally developed to minimum blob-density 21.6/100 μ. The other plate (full lines), was one from the Sardinia Flight S.30, and was subjected to clearing after processing in order to improve transparency, and keeping qualities. The minimum blob-density for this plate $b_{min}=14.1/100$ μ was inordinately low.

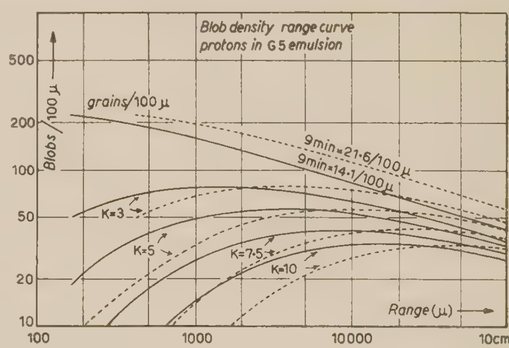

Fig. 3.

The curves were constructed as follows. For each plate, the $\overline{G}/R$ characteristic was established using a modified technique [3]. The g/R curve was computed using the relationship $\overline{G}=1/g-\alpha$ and the manufacturer's value $\alpha=0.27$ μ. For each value of K, the values for b/R curves were calculated by use of (5).

From these curves it will be seen that the position of the maximum depends strongly on K, and that the corresponding residual range increases with increasing physical development. For the normally developed plate for which K was found to be 7.5 it will be seen that the direction of motion may readily be found by inspection for protons of residual range $0 \leqslant R < 1$ cm, and that

useful mass comparisons may be made by blob-counting in this region. On the other hand, the cleared plates for which K was found to be 5, were quite useless for this purpose. In fact, by blob-counts alone, it is not possible to establish even the direction of motion of particles of protonic mass in the interval of residual range $1\text{ mm} \leqslant R \leqslant 1\text{ cm}$. In order to use such plates, it is necessary therefore to have recourse to other methods of estimating ionization such as the $\overline{G}$, R, the G, R, the photoelectric density-range or the older methods of estimating grain density. Difficulties of a like order arise if experimental values of b are used to estimate the residual range of particles emergent from stars.

It is clear from the foregoing, that the method of blob-density, although rapid and convenient, must be used with due regard to the limitations of its field of application. This field depends strongly on the development of the plate, so that it is important to decide beforehand as to suitable values of $b_{\min}$ and K. It appears that development to low values of these parameters is especially undesirable, not only for the reasons discussed above, but also because it renders very difficult the task of tracing fast particles through the stack of stripped emulsions.

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A New Method for Mass Measurements of Fast, Charged Particles.

S. ROSENDORF and G. YEKUTIELI
The Weizmann Institute of Science - Rehovoth, Israel

The mass of charged particles which do not come to rest in the emulsion has so far been measured by one method only, i.e. by the multiple-scattering v. grain-density method.

We have employed a new independent method to measure the mass of these particles, which is based on measuring the change of grain-density v. range

The grain-density of a track changes along its range according to the relation $f(R/M)$ where R is the range of the track in mm from the point where the grain-density is measured to the point where the particle comes to rest. M is the mass of the particle measured in units of protonic masses. Following the work of STEINHEIMER, we have calculated the variation of grain-density with range for protons with $1,2 \leqslant g^* \leqslant 1,8$ (g^* is the grain-density of the particles normalised to the plateau value). The grain-density in the major of this range can be written as a polynomial of the 4th order:

$$(1) \qquad f(R_0 + t) = 1.496 - 2.28 \cdot 10^{-3}\, t + 7.97 \cdot 10^{-6}\, t^2 - 3.55 \cdot 10^{-8}\, t^3 + 1.5 \cdot 10^{-10}\, t^4$$

$f(R_0 + t)$ is the normalised-to-plateau grain-density of a proton, (R_0+t) mm from its stopping point. $R_0 = 260$ mm. Let us consider a long secondary track ejected from a star and which does not come to rest in the emulsion. We shall use the middle point of its track as the origin to measure the range along the track. We want to know the mass, M, of the particle associated with this track, and the range, R, from its middle point. Denoting $V = 1/M$ and $R/M = U$, the normalised grain-density at a point X on the track, measured from its middle point, will be $f(U+VX)$. Next, the track is divided from its middle point to the rigth and to the left, into equal cells of $C = 0.5$ mm. The average grain density of the K-th cell to the left of the star will be g_K

and the grain-density of the K-th cell to the right will be g_{-K}. The distance of the end of the K-th cell from the middle of the track will be KC and the calculated grain-density for the point will be $f_K = f(U+VKC)$. The average grain-density for the whole track is:

$$g^* = \frac{1}{2N} \sum_{K=-N}^{N} g_K = \frac{1}{2N} \sum_{K=-N}^{N} f(U + VKC) \,. \tag{2}$$

It is assumed that the contribution of $(1/2N) \sum \eta_K$, where η_K (the statistical fluctuation of g_K) is neglected in (2). With the help of (1) we can express the left-hand side of (2) as a polynomial in U and V. There are only two terms in V: one V^2 and the other V^4. It can be shown that these two terms can be neglected in the first approximation. Therefore the only unknown in (2) is U. We solve (2) for U and find that in the first approximation the range of the middle point U_1 is equal to that of a proton with grain-density g^*.

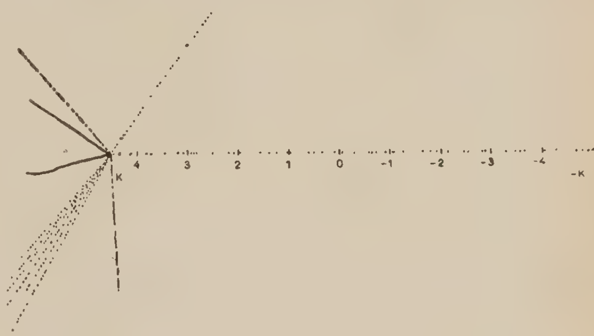

Fig. 1.

To find the actual values of U and V we use the principle of least squares. Let

$$\Phi = \sum_{K=-N}^{N} [g_K - f(U + VKC)]^2, \tag{3}$$

the actual values of U and V will be those roots of the equations

$$\frac{\partial \Phi}{\partial U} = 0 \quad \text{and} \quad \frac{\partial \Phi}{\partial V} = 0 \,, \tag{4}$$

which make Φ of (3) a minimum.

Inserting in $\partial\Phi/\partial V = 0$ the value $U = U_1$ from (2), we shall find V_1, which is a first approximation for V. In order to find the roots of (4) we shall expand (4) around U_1 and V_1:

$$\begin{cases} \left(\dfrac{\partial \Phi}{\partial U}\right)_{U_1V_1} + (U - U_1)\left(\dfrac{\partial^2 \Phi}{\partial U^2}\right)_{U_1V_1} + (V - V_1)\left(\dfrac{\partial^2 \Phi}{\partial U \partial V}\right)_{U_1V_1} = 0 \,, \\ \left(\dfrac{\partial \Phi}{\partial V}\right)_{U_1V_1} + (U - U_1)\left(\dfrac{\partial^2 \Phi}{\partial V \partial U}\right)_{U_1V_1} + (V - V_1)\left(\dfrac{\partial^2 \Phi}{\partial V^2}\right)_{U_1V_1} = 0 \,, \end{cases} \tag{5}$$

and both U and V are then found in a small number of steps.

The probable errors of U and V are given by

$$(6)\qquad \begin{cases} \Delta U = 0{,}675 \sqrt{\dfrac{A_U}{D}} \sqrt{\dfrac{\Phi_{\min}}{2N-2}} \\[2ex] \Delta V = 0.675 \sqrt{\dfrac{A_V}{D}} \sqrt{\dfrac{\Phi_{\min}}{2N-2}} \end{cases}$$

where D is the determinant of (5) and A_U and A_V are the corresponding co-tactors of U and V in (5). $\Phi_{\min}$ is the minimum number of (3) and $2N$ is the number of cells.

We have used this method to measure the mass of a K-particle with average grain-density $g^* = 1.41$ and of length 34 mm. The mass found according to the method described here was $840 \pm 140\ m_e$, compared with a value of $1230 \pm 110\ m_e$ found by the scattering v. grain-density method. Measurements on pions with the new method yield the results listed in the following Table I.

TABLE I.

No.	Length	g^*	Mass	Identity
89	10 mm	1.38	238 m_e	π
30	7 »	1.53	377 »	π

We believe that the method described here is useful for measuring the masses of particles which do not come to _est in the emulsion; but only when *a*) $g^* \geqslant 1.3$ of the plateau value, *b*) track length/mass > 6 cm and *c*) the plates are uniformly developed.

Relazioni dei Comitati speciali.

Report of the Committee on τ-Mesons.

E. AMALDI, E. FABRI, T. F. HOANG, W. O. LOCK, L. SCARSI, B. TOUSCHEK and B. VITALE

1. – Q-Value and Mass.

39 examples of τ-mesons observed in photographic emulsions have been collected in Table I (1). Of these 14 have been observed in usual nuclear plates while the remaining 25 have been observed in stripped emulsions. All the given τ-mesons appear to be coplanar within 1° or 2° and therefore we can assume that all the decays take place at rest.

The errors attached to the given Q-values are those reported by the corresponding authors. Unfortunately it is not always sure that the same curves (for instance range-energy relation) or the same values of the constants involved (for instance the mass of the π-meson) have been used.

In spite of that we have calculated a weighted average (2) of the Q-values for the usual nuclear plate data and for the stripped emulsions data separately. The values obtained are respectively

$$Q = 75.2 \pm 1.5 \text{ MeV} \quad \text{(usual nuclear plates)} \tag{1}$$

and

$$Q = 74.7 \pm 0.3 \text{ MeV} \quad \text{(stripped emulsions)}, \tag{2}$$

which are in satisfactory agreement.

For the reasons above mentioned as well as for some other possible sources of systematic error which have not been taken into account (for instance the

(1) A fortieth example — the last in Table I — has been added in proofs.

(2) Averages have been calculated with weights inversely proportional to the square of the relative errors.

TABLE I. – *Examples of τ-mesons in photographic emulsions (usual and stripped).*

Primary							Secondary						Q (MeV)	Notes
Particle	Range (mm)	E (MeV)	Parent star	ϑ_p	Sign	Time of flight (s)	Range (mm)		E (MeV)	Sign	Angles			
τ-Bo_1 strip.	3.67	6.4	$21+2\alpha$		+	$5.6\cdot10^{-11}$	*a*		33.7	(—)	α	101°	76.7 ± 2.0	$m_\pi = 276$ m_e *Proc. Ind. Ac. Sci.*, **38**, 398 (1953).
							b		26.2	+	β	122°		
							c		16.8	+	γ	137°		
τ-Bo_2 strip.	6.65	31.7	6+0p			$9.2\cdot10^{-11}$	*a*		37.9		α	86°	75.3 ± 1.7	» »
							b		21.8	+	β	133°		
							c		15.6	—	γ	142°		
τ-Bo_3 strip.	7.47	33.6	$13+10\alpha$			$1.0\cdot10^{-10}$	*a*		38.8		α	79°	75.3 ± 2.4	» »
							b		29.9		β	119°		
							c		6.6	+	γ	162°		
τ-Br_1	3.1						*a*		33 ± 4		α	86°	65 ± 8	$m_\pi = 274$ m_e *Nature*, **163**, 82 (1949).
							b		31 ± 4		β	103°		
							c		1.04	—	γ	170°		
τ-Br_2	2.07						*a*		32 ± 2		α	103°	75 ± 5	$m_\pi = 274$ m_e *Phil. Mag.*, **42**, 1040 (1951).
							b		24.4		β	124°		

τ-Br_3							*b*				β			Communication at Padua meeting.
							c				γ			
τ-Br_4 strip.	13.9						*a*				α		78 ± 6	Too dipping tracks. Communication at Padua meeting.
							b				β			
							c	3.4	12.2	+	γ			
τ-Br_5 strip.	25.9	70	5+1n		+	$2.5 \cdot 10^{-10}$	*a*	> 21.6	41.3	(—)	α	70°	74.2	(Br_5 - Br_9: $m_\pi = 273\ m_e$). Communication at Padua meeting.
							b	5.55	16.9	+	β	144°		
							c	5.02	16	+	γ	146°		
τ-Br_6 strip.	57.3	110	9+0p			$4.8 \cdot 10^{-10}$	*a*	> 11.0	39.0		α	75°	75.2	Communication at Padua meeting.
							b	18.63	34.0	—	β	116°		
							c	0.17	2.2	+	γ	169°		
τ-Br_7 strip.	48.5	101	21+1n			$4.2 \cdot 10^{-10}$	*a*	21.1	36.6	—	α	87°	73.5	» »
							b	> 7.65	24.9		β	127°		
							c	3.07	12.0	+	γ	146°		
τ-Br_8 strip.	26.0						*a*	23.9	38.6	—	α	79°(*)	75.3	» »
							b	> 2,1	34.9		β	111°(*)		
							c	0.107	1.7	+	γ	170°(*)		

(*) The angles were calculated by the Committee.

TABLE I (*continued*).

Primary							Secondary						Q (MeV)	Notes
Particle	Range (mm)	E (MeV)	Parent star	ϑ_p	Sign	Time of flight (s)		Range (mm)	E (MeV)	Sign	Angles			
τ-Br_9 strip.	4.9						a	25.6	42.3	—	α	32°(*)	75.7	Communication at Padua meeting.
							b	> 4.9	31.8		β	153°(*)		
							c	0.098	1.63	+	γ	175°(*)		
τ-It_1							a				α			P. H. BARRET: private communication.
							b				β			
							c				γ			
τ-Loi_1	0.74						a		45 ± 12		α	53°	75.8 ± 15	$m_\pi = 274\ m_e$ *Phil. Mag.*, **41**, 405 (1950).
							b		17.5 ± 8		β	151°		
							c		13.3 ± 3		γ	156°		
τ-Loi_2							a		25 ± 5		α	115°	69 ± 8	$m_\pi = 274\ m_e$ *Phil. Mag.*, **41**, 405 (1950).
							b		24 ± 4		β	118°		
							c		20 ± 4		γ	127°		
τ-Loi_3							a		33.5 ± 5		α	101°	73.5 ± 7	$m_\pi = 274\ m_e$ *Phil. Mag.*, **42**, 1060, (1951).
							b		31.0 ± 4		β	108°		

τ-Mn_1	1.7						b		15.5		β	158°	78.5 ± 5	*Proc. Roy. Soc.*, **221**, 391 (1954)
							c		15		γ	158°		
τ-Mn_2	1.69						a	$> 0,5$	51		α	53°	90	I. W. MAJOR: private communication.
							b	> 0.05	36		β	139°		
							c	0.527	4.3	+	γ	167°		
τ-Mi_1	4						a		42.4		α	43°	75.2 ± 7	$m_\pi = 277\ m_e$ *Nuovo Cimento*, **10**, 687 (1953)
							b		30.6		β	144°		
							c		2.2	+	γ	171°		
τ-Mi_2 strip.	14.2	50	11+10n		+	$1.5 \cdot 10^{-10}$	a		35.8	+	α	98°(*)	76.1 ± 1.0	$m_\pi = 277\ m_e$ Communication at Padua meeting.
							b		34.7	−	β	99°(*)		
							c		5.84	+	γ	163°(*)		
τ-Bth_1 strip.							a		45		α	44°(*)	77.9	H. YAGODA: private communication.
							b		29	+	β	146°(*)		
							c		3.9	+	γ	170°(*)		
τ-Ep_1 strip.	3.9	24	21+0n			$3 \cdot 10^{-11}$	a	> 3.5			α	118°	71.3 ± 22 (*E* v. *R* from VIGNERON)	Communication at Padua meeting.
							b	> 4.5			β	120°		
							c	9.6	22.5	+	γ	122°		

(*) The angles were calculated by the Committee.

TABLE I (*continued*).

Primary							Secondary						Q (MeV)	Notes
Particle	Range (mm)	E (MeV)	Parent star	ϑ_v	Sign	Time of flight (s)		Range (mm)	E (MeV)	Sign	Angles			
							a	20.5	35.3	+	α	86°		Communication at Padua meeting.
τ-Ep_2 strip.	10	40	5+2n		+	$1.2\cdot10^{-10}$	b	15.5	30.1	+	β	115°	72.3 ± 1.7	
							c	1.14	6.9	—	β	158°		
							a		41.6		α	91_o		$m_\pi = 274\ m_e$
τ-Pd_1	8						b		27,8		β	127°	86.5 ± 5	*Nature*, **170**, 454, (1952).
							c		17.1		γ	142°		
							a		30.3		α	103°		$m_\pi = 273\ m_e$
τ-Pd_2	7.3	33	2+n			$1\cdot10^{-10}$	b		30		β	115°	78 ± 5	*Nuovo Cimento*, **10**, 681 (1953).
							c		17.9		γ	142°		
							a	25.2 ± 0.3	40.5	+	α	72°		$m_\pi = 273\ m_e$
τ-Pd_3 strip.	6.7	32	21+13p	17°	+	$0.9\cdot10^{-10}$	b	12.9 ± 0.1	27.4	+	β	130°	75.0 ± 1.1	Communication at Padua meeting.
							c	1.3 ± 0.01	7.1	—	γ	158°		
							a	> 9.0	34.2		α	100°		$m_\pi = 273\ m_e$
τ-Pd_4 strip.	7.4	35	10+1p	40°		$1.0\cdot10^{-10}$	b	12.3 ± 0.5	26.4	—	β	120°	76.0 ± 1.5	Communication at Padua meeting

τ-Pd_5 strip.	12.1	45	16+4n			$1.4\cdot10^{-10}$	*b*	9.2±0.5	22.5	—	β	128°	75.6±2.0	Communication at Padua meeting.
							c	7.2±0.4	19.6	+	γ	132°		
τ-Ro_1	1.6						*a*		40.3		α	78°	79.9±2.9	$m_\pi = 277\ m_e$ *Nuovo Cimento*, **10**, 937 (1953).
							b		34.6		β	121°		
							c		5.0	+	γ	161°		
τ-Ro_2	1.1						*a*		36.5		α	84°	71.5±4	$m_\pi = 277\ m_e$ *Nuovo Cimento*, **10** 937 (1953).
							b		18.5		β	135°		
							c		16.5		γ	141°		
τ-Ro_3 strip.	13	46	5+5	83°		$1.4\cdot10^{-10}$	*a*		40.6		α	73°(*)	74.4±1.3	$m_\pi = 273\ m_e$ Communication at Padua meeting.
							b		19.4	+	β	139°(*)		
							c		14.4	—	γ	148°(*)		
τ-Ro_4 strip.	9.1	38	1+14α	59°	+	$1.1\cdot10^{-10}$	*a*		46.2	+	α	31°(*)	74.2±0.4	Communication at Padua meeting.
							b		14.1	—	β	164°(*)		
							c		13.9	+	γ	165°(*)		
τ-Ro_5 strip.	13.6	47	4+0p	59°		$1.4\cdot10^{-10}$	*a*				α	76°(*)	74.1±0.9	» »
							b		24.1	—	β	132°(*)		
							c		10.5	+	γ	152°(*)		

(*) The angles were calculated by Committee.

TABLE I (*cotinuned*).

Particle	Primary: Range (mm)	Primary: E (MeV)	Primary: Parent star	Primary: ϑ_p	Primary: Sign	Primary: Time of flight (s)	Secondary	Secondary: Range (mm)	Secondary: E (MeV)	Secondary: Sign	Secondary: Angles		Q (MeV)	Notes
τ-Ro_6 strip.	5.3	30	8+7p	150°	+	$1.5\cdot10^{-11}$	*a*		41		α	77°(*)	77±4	Communication at Padua meeting.
							b		27	+	β	129°(*)		
							e		9.5	+	γ	154°(*)		
τ-Rc_1 strip.	60.6	116	12+0p			$5\cdot10^{-10}$	*a*	> 10	> 24		α			» »
							b	> 10	> 24		β			
							c	1.4	7.65	—	γ			
τ-Rc_2 strip.	61.3	117	5+0n			$5\cdot10^{-10}$	*a*	20.1 (estimated)	36.7		α	80°	73.6±1.0 from energy balance	» »
							b	19.6	35.4	—	β	110°		
							c	0.086	1.5	+	γ	169°	$75.3^{+3.6}_{-2.5}$ from momentum balance	
τ-To_1 strip.	34	75	15+8n		+	$3.7\cdot10^{-10}$	*a*	20.2	35.4	+	α	93°	74.7±1.0	*Nuovo Cimento*, 11, 420 (1954).
							b	10.7	24.5	—	β	125°		
							c	4.5	14.8	+	γ	141°		

							a	26.8	41.7	—	α	47°		*Nuovo Cimento*, **11**, 420 (1954).
τ-To_2 strip.	16.4	50	7+8p		+	$2.2 \cdot 10^{-10}$	b	14.6	29.4	+	β	144°	74.3 ± 1.0	
							c	0.32	3.22	+	γ	169°		
							a	> 0.3	43		α	98°		K. GOTTSTEIN: communication at Padua meeting.
τ-Go_1	> 2	> 16				$>3.7 \cdot 10^{-11}$	b	> 0.4	40		β	109°	96 ± 10	
							c	> 0.4	14		γ	152°		
							a		34.8		α			M. SCHEIN: private communication.
τ-Ch_1 strip.	> 2.05	> 16					b		23.0		β		74.4	
							c		16.6		γ			

(*) The angles were calculated by the Committee.

inelastic scattering of π-mesons) we think that the above errors are certainly underestimated.

From the given Q-value we obtain for the mass of the τ-meson

$$(3) \qquad m_\tau = 2m_{\pi^+} + m_{\pi^-} + Q = (819.3 \pm 0.4) + Q = (965.5 \pm 0.7)\ \mathrm{m}_e\,.$$

We repeat our remark about the possible uncertainty in the estimation of the error.

2. – Frequency of Production.

The data relating to the frequency of production of τ-mesons in the emulsions exposed (for about 8 hours at 25 000 m on sea-level) during the Sardinia Expedition 1953 is summarized in Table II, which is limited to the cases in which the given volume was systematically scanned.

TABLE II. – *Frequency of observations of π, τ and K-mesons.*

Laboratory	Volume (cm³)	Number, N, of particles			
		N_π	N_τ	$N_{(\tau)K_\pi}$	N_K
Milan	16.5	584	1	1	5
Padua	51	2 200	2	1	8
Paris	24	1 018	2	1	12
Rome	27	1 250	4	—	—

$$\frac{N_\tau}{N_\pi} = \frac{9}{5\,052} = 1.8\cdot 10^{-3}; \quad \frac{N_\tau}{N_K} = \frac{5}{25}; \quad \frac{N_\tau}{N_{(\tau)K_\pi}} = \frac{5}{3}; \quad n_\tau = 7.7\cdot 10^{-2}\ \mathrm{cm}^{-3}$$

It is perhaps interesting to note that all the 9 τ-mesons observed to stop in the stripped emulsions, originated from stars inside the same stack.

3. – Charge.

Table III contains all information that we have at present on the charge of the τ's observed in emulsion. We like to add the following remarks:

a) no negative and 9 certainly positive τ-mesons [6(++−) and 3(++)] have been observed;

b) if all the τ-mesons decaying in the emulsion are positive and there is no bias for the observation of the unlike particles (π^-) with respect to the two

equal ones (π^+) we have to expect to observe twice as many events in class $(+-)$ than in class $(++)$ and twice as many events in class $(+)$ than in class $(-)$. The data given in Table III are not inconsistent with such an interpretation.

TABLE III. – *Existing evidence on the sign of the charge of τ-mesons.*

Class	Number of particles	Average energy (MeV)	Particles
$(++-)$	6	—	Mi_2, Ep_2, Pd_3, Ro_4, To_1, To_2
$(++)$	3	27; 14	Br_5, Ro_6, Bo_1
$(+-)$	11	12(+); 27(—)	Bo_2, Br_6, Br_7, Br_8, Br_9, Bth_1, Pd_4, Pd_5, Ro_3, Ro_5, Rc_2
$(+)$	6	8.8	Bo_3, Br_4, Mn_2 (*), Mi_1 (*), Ep_1, Ro_1 (*)
$(-)$	2	4.3	Br_1 (*), Rc_1

(*) These events have been found in glass-plates.

c) if one tries to apply statistical considerations to the classes $(++-)$, $(++)$, $(+)$ and $(-)$ one finds that the probability p that one of the τ-mesons decaying in the emulsion be positive, is probably not smaller than 88%. The quantity $q=1-p$ is obviously related to the nuclear capture probability of negative τ. From the above consideration it can only be stated that q is smaller than 12%; we will however assume in the following $q=0$, i.e. that all the τ-mesons observed to decay in emulsions are positive.

According to PEYROU, cloud chamber workers have observed so far

$$7\ \tau^+$$

and

$$3\ \tau^-\ \text{(1 certain and 2 uncertain)}$$

decaying in flight (*). The statistics are very poor but indicate a slight positive excess in the production process.

(*) Manchester 1+; Pasadena 2+; 1—; Jungfrau 2+; Pic-du-Midi 2+; 2— (?).

4. – Spin and Parity.

Some very scanty information about the spin and parity of τ-mesons is also available. Table IV contains the distribution of the observed events with

TABLE IV. – *Energy spectrum of negative π's produced in τ-meson decay.*

$E_- > E'_+, E''_+$	$E''_+ > E_- > E'_+$	$E''_+, E'_+ > E_-$
Bo_1 (*)	Br_6	Bo_2
Br_5 (*)	Mi_1 (*)	Bth_1
Br_7	Pd_4	Pd_2 (*)
Br_8	Pd_5	Pd_3 (*)
Br_9	Ro_4 (*) (+)	Ro_3
Ro_6 (*)	Ro_5	
To_2 (*)	Rc_2	
	To_1 (*)	
No. of the events 7	No. of the events 8	No. of the events 5

(*) For these events the charge of all three π-mesons is known while for the others it is necessary to assume that all τ are positive. The events Br_1 and Rc_1 for which only one of the three π-mesons was observed to stop in the emulsion (negative charge and very low energy) belong certainly to the third column. They have been excluded in order to reduce the experimental bias.

(+) This event has a probability of 69 % to belong to this class and 31 % to belong to the third one.

respect to the energy of the negative π under the assumption that all τ are positive. These data could be influenced by some experimental bias. In spite of that a χ^2-test has been made in order to compare such a distribution with

TABLE V (*). – *χ^2-test for spin and parity determination.*

Spin and parity	69 %		31 %	
	χ^2	$\mathcal{P}$	χ^2	$\mathcal{P}$
(0 —)	< 0.7	0.70	< 0.05	$1-\varepsilon$
(1 +)	2.9	0.24	4.4	0.11
(1 —)	3.1	0.22	4.4	0.11
(2 +)	5.7	0.06	4.5	0.11
(3 —)	0.3	0.85	0.45	0.80

(*) For each assumption we give two values of χ^2 and $\mathcal{P}$ because of the uncertainty about Ro_4 (see Table IV).

that predicted on the basis of various assumptions on the spin and parity of the τ-meson. The results are collected in Table V where the χ^2-test and the corresponding PEARSON probability $\mathcal{P}$ are given.

5. – Mean Life.

The total moderation time of 21 τ-mesons observed in stripped emulsions amounts to $4.2 \cdot 10^{-9}$ s. Therefore the 39 events observed correspond to a total moderation time of not less than $8 \cdot 10^{-9}$ s. In this time no decay in flight has been observed. In deriving any conclusion from these data, one has to keep in mind the possible existence of some experimental bias.

On the other hand from the analysis of cloud chamber data presented by GREGORY it appears that the mean life of the τ-meson is not very different from that of the K-particle which is, according to these authors, about $2.8 \cdot 10^{-8}$ s. One can conclude that the mean life of the τ-meson is probably not shorter than 10^{-8} s.

6. – Possible Evidence for an Alternative Mode of Decay.

We give in Table VI the few cases of K-mesons (so called $^{(\tau)}K_\pi$ or τ') apparently decaying into a π-meson which is brought to rest inside the emulsion, with momentum less than 125 MeV/c (see in this issue, pag. 433). Such a selection has to be kept in mind in the following. Some of the events in this table could be due to nuclear capture with emission of the π-meson and only neutral particles. The event K-Ro$_1$ belongs very probably to this class, while the remainder can be more probably attributed to decay processes.

One can see that the energy of the emitted π is always compatible with the assumption that all these events are due to the alternative mode of decay of the τ-meson:

$$\tau^\pm \to \pi^\pm + 2\pi^0 \, .$$

The weighted average mass of the particles given in Table VI turns out to be

$$m_{(\tau)K_\pi} = 1030 \pm 35 \, m_e \, ,$$

which agrees with the value (3).

If this interpretation is correct and not due to the type of selection used, a comparison of the frequency of observations of this class of events with the class of $\tau \to 3\pi^\pm$ particles allows us to determine the corresponding branching ratio. In order to do that it is necessary to take into account various experimental bias which affect strongly the probability of observation of these events. An analysis made by the Milan group and reported by C. C. DILWORTH suggests that the branching ratio

$$(\tau^+ \to \pi^+ + \pi^0 + \pi^0)/(\tau^+ \to 3\pi^\pm)$$

lies between 1/3 and 1/5 which is compatible with the theoretical prediction of DALITZ.

TABLE VI. – $^{(\tau)}K_\pi$. *In this Table we collect all the K-particles decaying in a π stopping in the emulsion with momentum less than* 125 MeV/c.

PRIMARY									SECONDARY			
$^{(\tau)}K_\pi$ Particle	Range (mm)	Mass (α, R) (m_e)	Mass (g, R) (m_e)	Average Mass (m_e)	E (if τ) (MeV)	Parent star	ϑ_p	Time of flight (s)	Range (mm)	E (MeV)	Sign	Notes
It_1	0.32							$> 1\cdot10^{-11}$		4.3	+	P. H. BARRET: private communic.
Mi_1	6.83				32	17+7p		$9.6\cdot10^{-11}$		41.5	+	Primary very dipping. Communicat. at Padua meeting.
Ep_1	6.8		930 ± 100		32	21+1p		$9.6\cdot10^{-11}$	9.7	22.7	+	Communication at Padua meeting.
Pd_1	13.0	966 ± 100			46	8+3n		$1.5\cdot10^{-10}$	0.9	6.0	+	» »
Ro_1	12.1		1060 ± 50		45	17+6n		$1.4\cdot10^{-10}$		44.5 ± 2.5	−	*Nuovo Cimento*, **11**, 207 (1954) (*).
Rc_1	16.0	975 ± 170	940 ± 100	950 ± 85				$> 1.8\cdot10^{-10}$	4.3	14.7 ± 0.26	+	Communication at Padua meeting.
Rc_2	13.8	1550 ± 100	995 ± 100	1060 ± 100	48	2+0p or 2+1n		$1.6\cdot10^{-10}$	4.6	15.2 ± 0.37	+	» »

(*) This event can also be interpreted as a K^- capture with emission of a negative π and only neutral prongs.

Report of the Committee on K-Particles.

C. C. Dilworth, A. Manfredini, G. D. Rochester
J. Waddington and G. T. Zorn

1. – Nomenclature.

The following nomenclature is used throughout this report. K is a particle with a mass between the L-meson and the proton. A superscript + or — or indicates the sign when known. ρK denotes a K-particle which stops in the emulsion without producing a visible track: σK a K-particle which stops and produces a visible nuclear disintegration.

The following subclasses will be used:

Charged particles $K^{\pm}$.

$\varkappa$ A K-particle which decays into a μ-meson and at least two neutral particles.

$K_{(\gamma)}$ A K-particle whose disintegration into a light meson is associated with the observation of at least one γ-ray.

K_{μ} A K-particle of mass $920 \pm 20\ m_e$ which decays into a μ-meson of unique momentum, 222 MeV/c, i.e. $p\beta = 197$ MeV/c.

K_{π} A K-particle which decays into a π-meson of momentum greater than 125 MeV/c, i.e. greater than the alternative mode of the τ-meson (see § 6 of the *Report of the Committee on τ-Mesons*, in this issue, pag. 419).

K_e A K-particle which decays into an electron.

K_L A K-particle wich decays into a ligth meson.

Neutral Particles K^0.

K^0 All neutral K particles.

θ^0 A K^0-particle of mass $966 \pm 10\ m_e$ which decays into two π-mesons (decay to one π-meson and one μ-meson is not excluded).

2. – Evidence for K-Particles.

i) *The $\varkappa$-Meson.* – Suggested mode of decay [1]:

$$\varkappa \to \mu + ? + ? \, .$$

The direct evidence for this decay scheme consists in the observation of four K-decays in which the μ-meson subsequently decays to an electron. These μ-mesons have the following values of $p\beta$ (and kinetic energy): 11.8 MeV/c (6 MeV) Bristol, 25.8 MeV/c (13.6 MeV) Rome, 50 MeV/c (28 MeV) Rochester, and 57.5 MeV/c (33.3 MeV) Paris. In addition there are a number of secondaries of K-decays which, when examined by the method of scattering v. grain-density, seem to be μ-mesons and show a wide spread in values of $p\beta$.

ii) *The* $K_{(\gamma)}$*-meson.* – Suggested mode of decay:

$$K_{(\gamma)} \to L + \gamma + ?$$

or

$$K_{(\gamma)} \to L + \pi^0 \, .$$

The evidence for this form of decay comes from the multiplate cloud chamber experiments by the Massachusetts Institute of Technology group [2]. There are 9 cases out of forty (see ANNIS, pag. 314 of this issue) in which γ-rays have been observed associated with the decay of S-particles to L-mesons. The γ-rays are observed in the backward hemisphere and their angular distribution is consistent either with their being the direct product of the disintegration of the S-particle in a three-body decay or thedecay of a neutral π-meson emitted in a two-body decay of the S-particle.

iii) *The* K_μ*-meson.* – Suggested mode of decay:

$$K_\mu \to \mu + \nu \, .$$

The evidence for this form of decay comes from the double cloud chamber experiment of the École Polytechnique group [3].

iv) *The* K_π*-meson.* – Suggested mode of decay:

$$K_\pi \to \pi + ? + (?) \, .$$

The evidence for this particle includes the evidence for the Bristol χ-meson [1], which was considered to give a π-meson of unique momentum $p = 206$ MeV/c

($p\beta = 167$ MeV/c) for a χ-particle of mass 966 m_e and a π-meson of mass 273 m_e. Two further suggested examples have been reported by the Padua group [25] at the Conference with $p\beta$-values of 160 ± 10 MeV/c and 159 ± 9 MeV/c.

v) *The* K_e*-meson.* – Suggested mode of decay:

$$K_e \rightarrow e + ? + (?) .$$

One *provisional* case of this type of decay has been reported at the Conference by Bristol [4]. The value of $p\beta$ of the electron is 67 MeV/c.

vi) *The* θ^0*-meson.* – Suggested mode of decay:

$$\theta^0 \rightarrow \pi^{\pm} + (\pi^{\mp} \text{ or } \mu^{\mp}) + Q .$$

The mass value 966 ± 10 m_e assumes decay to two π-mesons and is based on 20 examples observed in the cloud chamber by THOMPSON *et al.* of Indiana [5]. The Q-value is 214 ± 5 MeV.

vii) *The other* K^0*-mesons.* – Under this heading are grouped all cases of V^0-decay other than θ^0-mesons which are observed in cloud chambers and which lead to mass values less than the proton mass. If these cases are interpreted according to the θ^0 (π, π) decay scheme, give Q-values very different from 214 MeV. The California Institute of Technology group have described six such events [6], THOMPSON *et al.* [5] have found two, and others have been observed by the Princeton [7] and Pic-du-Midi [8] groups. Many of these events can be explained by one or two three-body decay schemes, for example, $K^0 \rightarrow \pi + \mu + \nu$ or $K^0 \rightarrow \pi^{\pm} + \pi^{\mp} + \pi^0$, but some of the events seem to involve secondary particles heavier than π-mesons. The difficulties inherent in the observation of such rare events in the presence of a relatively large population of θ^0 and $K^{\pm}$-decays in arrangements of differing geometry have been pointed out by ASTBURY [9].

3. – Masses of the K-Particles.

i) *Emulsion Results from Different Methods.* – The detailed mass measurements reported to date by the various emulsion groups are given in Table I.

TABLE I. – *Data on* K-*mesons* (°).

PRIMARY						SECONDARY			
K Particle	Parent star	Range (mm)	Time of flight (in 10^{-9}s)	Mass in m_e (g, R)	Mass in m_e (α, R)	Length (mm)	g^*	$p\beta$ (MeV/c)	Mass (m_e)
Bk_1	?	9.0	0.1068	—	850 ± 200	—	steep	—	—
Bo_1 (*)	20+5n	13.7	0.1462	950 ± 100	955 ± 140	—	—	226 ± 20	—
Bo_2 (*)	14+2n	11.3	0.1232	1120 ± 100	980 ± 155	—	$.96\pm.12$	—	—
Bo_3 (*)	?	5.4	0.0744	1115 ± 100	1025 ± 95	—	1	—	—
Bo_4 (*)	1+2n	32.0	0.2618	980 ± 100	740 ± 85	—	$.93\pm.07$	—	—
Bo_5 (*)	$8+2\alpha$	13.3	0.1386	865 ± 100	1005 ± 170	—	—	—	—
Bo_6 (*)	21+3p	5.0	0.0704	—	1050^{+280}_{-200}	25.0	$1.045\pm.02$	240 ± 25	—
Br_1	?	4.1	0.0622	1380 ± 180	1260 ± 260	2.2	$.97\pm.04$	235 ± 35	μ (π,e)
Br_2	?	5.67	0.0782	1125 ± 150	1125 ± 230	1.1	—	11.8	μ
Br_3	?	0.53	0.0138	—	1000 to 2000	5.9	$.96\pm.026$	144 ± 12	μ (e)
Br_4	?	2.1	0.0368	—	1370 ± 320	0.17	1	—	—
Br_5	?	1.54	0.0286	950 ± 200	1220 ± 400	8.9	$1.705\pm.083$	66 ± 11	μ (π)
Br_6	?	2.55	0.0442	1050 ± 200	1036 ± 280	0.1	1	—	—
Br_7	?	0.38	0.0114	—	1000	2.5	$1.09\pm.05$	170 ± 29	π (μ)
Br_8	?	2.55	0.0418	900 ± 200	1460 ± 320	7.65	$1.14\pm.025$	187 ± 17	π
Br_9	?	0.63	0.0168	—	1000	19.5	$1.094\pm.016$	162 ± 9	π
Br_{10}	?	1.38	0.0286	—	1100 ± 330	0.275	1	—	—
Br_{11}	?	0.54	0.0153	—	1300	0.1	1	—	—
Br_{12}	?	13.2	0.1386	—	1210 ± 150	0.15	1	—	—
Br_{13}	?	0.96	0.0224	—	1089 ± 450	0.2	1	—	—
Br_{14}	?	3.44	0.0536	—	925 ± 190	0.5	$1.02\pm.10$	120 ± 44	μ (e, π)
Br_{15}	?	9.56	0.1152	—	1100 ± 170	4.1	$1.028\pm.031$	184 ± 30	π (μ, e)
Br_{16}	?	1.7	0.0314	—	1000	2.8	$1.030\pm.045$	153 ± 24	μ (π)
Br_{17}	?	4.31	0.0644	—	1200 ± 230	6.5	$1.15\pm.03$	172 ± 17	π
Br_{18}	?	1.85	0.0342	—	1500	4.0	1	315 ± 70	μ (π, e)
Br_{19}	?	1.02	0.0224	—	1000 to 2000	2.8	1	125 ± 35	μ (π, e)
Br_{20}	?	6.675	0.0858	—	990 ± 150	0.18	1	—	—
Br_{21}	1+0n	0.35	0.0105	—	—	18.0	$0.93\pm$	205 ± 5	μ
Br_{22} (*)	1+0p	28.0	0.2384	780 ± 90		6.0	$1.09\pm.04$	170 ± 20	280 ± 20
Br_{23} (*)	19+3n	7.56	0.0930	990 ± 150	—	3.0	—	—	—
Br_{24} (*)	10+0p	8.56	0.1034	1200 ± 200	1400 ± 200	54.0	1.2 to 1	119 ± 9	203 ± 8
Br_{25} (*)	24+3p	3.77	0.0580	1000 ± 250	1150 ± 250	0.5 per plate	—	—	—
Br_{26} (*)	19+24	42.1	0.3170	990 ± 55	1100 ± 150	—	~1	>100	—
Br_{27}	?	~8	0.1000	—	—	—	—	—	—
Br_{28}	?	~8	0.1000	—	—	—	—	—	—
Br_{29}	?	~1.3	0.1386	—	1000	—	—	—	—
Br_{30} (*)	?	40	0.3064	—	—	Energy 50-60 MeV estimated from change in grain dens.			—
Br_{31} (*)	13+3p	19.09	0.1814	900 ± 200	—	—	~1	145 ± 25	—

(°) We wish express our gratitude to the Editors of Annual Review of Nuclear Science who gave permission for the inclusion of these Tables, which were compiled by C. DILWORTH and L. SCARSI, for an article on Heavy Mesons to appear in Volume IV of their Reviews. (*) Stripped emulsions.

BLE I (*continued*).

K article	PRIMARY Parent star	Range (mm)	Time of flight (in10^{-9}s)	Mass in m_e (g, R)	(α, R)	SECONDARY Length (mm)	g^*	$p\beta$ (MeV/c)	Mass (m_e)
Br$_{32}$ (*)	27+3p	19.18	0.1814	—	—	—	—	—	—
Br$_{33}$ (*)	7+5p	4.03	0.0602	850±200	—	—	~1	112±20	—
Br$_{34}$ (*)	23+13p	—	—	—	—		steep	—	—
Br$_{35}$ (*)	15+5p	48.36	0.3064	910±200	—	—	—	—	—
Br$_{36}$ (*)	—	—	—	—	—	—	—	—	—
Br$_{37}$ (*)	4+1n	~8	0.1000	—	720±200	provisional results		67	poss.elec.
Br$_{38}$ (*)	11+4p	18.81	0.1746	1200±200	—	—	—	—	—
Br$_{39}$ (*)	?	23	0.2012	900±200	—	—	—	—	—
Br$_{40}$ (*)	—	—	—	—	—	—	—	—	—
Br$_{41}$ (*)	19+3n	39.0	0.2954	~ 950	—	—	—	—	—
GeMi$_1$	?	2.0	0.3690	—	1270±290	3.44	0.94±.03	150±27	—
GeMi$_2$	30+8α	5.26	0.0744	1050±140	1030±165	0.45	1.15±.1	—	—
GeMi$_3$	36+6p	1.88	0.0342	1170±270	1540±380	2.08	1.14±.03	108±18	190±32
GeMi$_4$	?	1.47	0.0286	—	1360±340	2.5	1.06±.04	200±33	300±50
GeMi$_5$	?	0.64	0.0168	—	1000	—	—	—	—
GeMi$_6$	?	3.4	0.0536	980±290	1010±200	—	—	—	—
GeMi$_7$	?	12.57	0.1350	—	1100+165	0.6	1	—	—
GeMi$_8$(*)	4+0n	5.69	0.0782	—	1380±270	—	short	—	—
GeMi$_9$(*)	7+0p	19.24	0.1814	—	1015±160	51.0	1.12±.012	135±7	—
GeMi$_{10}$(*)	?	18.5	0.1746	—	1025±200	40.0	0.97±.012	150±10	—
GeMi$_{11}$(*)	10+7p	18.33	0.1746	—	900±125	53.0	0.97±.13	190±15	—
GeMi$_{12}$(*)	4+2p	15.85	0.1534	—	850±120	60.0	1.21±.025	146±10	—
GeMi$_{13}$(*)	16+0p	9.4	0.1068	—	870±165	—	steep	—	—
Bx$_1$	?	3.0	0.0490	—	800±160	—	—	—	—
Bx$_2$	?	2.0	0.0368	—	750±170	—	—	—	—
Bx$_3$	?	1.4	0.0286	—	985±255	—	—	—	—
Bx$_4$	?	20.0	0.1880	—	1100±110	5.0	1.09	200+30	—
t$_1$	?	5.0	0.0704	—	1020±140	0.2	1.12±.11	—	—
t$_2$	?	0.52	0.0138	—	—	4.7	1.07±.03	172±26	280±50
t$_3$	?	0.12	0.0051	—	—	2.5	2.75±.08	24.5±25	191±30
t$_4$	?	11.3	0.1232	1080±150	1000^{+260}_{-190}	0.13	1	—	—
t$_5$	?	10.4	0.1152	1030±250	1190±400	0.34	1.15±14	—	—
t$_6$	?	1.7	0.0314	—	1000	0.25	1.56±.14	—	—
t$_7$	?	0.44	0.0122	—	—	0.64	1.1±.1	111±35	190±60
Co$_1$ (*)	?	1.4	0.0286	—	1680^{+760}_{-520}	21.0	0.93±.02	190±20	—
Co$_2$ (*)	?	0.3	0.0097	—	—	—	—	—	—
Co$_3$ (*)	12+2p	3.0	0.0490	1110±160(°)	1100±300	64.0	0.96±.015	223±22	poss. π
Co$_5$ (*)	11+12p	30.0	0.2502	—	970±210	58.0	1.02±.02	167±8	prob. π
Co$_6$ (*)	6+1p	5.3	0.0744	1000±40	880±160	—	steep	—	—
Co$_7$ (*)	16+2n	44	0.3276	—	1630±160	34	—	—	—
Co$_8$ (*)	23+9p	15.0	0.1534	—	—	—	steep	—	—

(°) Measured by photometric method. (*) Stripped emulsions.

TABLE I (*continued*).

Primary						Secondary			
K Particle	Parent star	Range (mm)	Time of flight (in10^{-9}s)	Mass in m_e (g, R)	Mass in m_e (α, R)	Length (mm)	g^*	$p\beta$ (MeV/c)	Mass (m_e)
O_{s_1}	16+3p	14.0	0.1462	—	1090 ± 180	2.5	1.05 ± .03	126 ± 21	200 ± 2
Mn_3	?	3.28	0.0512	1000 ± 150	1030 ± 300	9.1	1.010 ± .05	124 ± 12	—
Pd_1	29+4n	0.29	0.0168	—	—	0.6	1.05 ± .05	158 ± 53	—
Pd_2	21+2n	2.6	0.0440	—	1030 ± 320	0.2	1.03 ± .2	—	—
Pd_3 (*)	20+7n	42.5	0.3170	964 ± 60	—	21.0	—	160 ± 10	270 ± 3
Pd_4 (*)	15+1p	19.14	0.1814	975 ± 200	961 ± 122	40.0	—	110 ± 15	—
Pd_5 (*)	4+1p	19.31	0.1814	1006 ± 100	920 ± 330	37.5	—	70 ± 16	—
Pd_6 (*)	14+11p	17.24	0.1676	850 ± 100	865 ± 290	44.4	—	52 ± 20	—
Pd_7 (*)	5+1p	36.5	0.2844	943 ± 60	948 ± 100	24.0	—	159 ± 9	276 ± 3
Pd_8 (*)	15+7α	26.93	0.2262	1180 ± 140	895 ± 225	—	—	190 ± 40	—
Pd_9 (*)	17+2p	12.0	0.1310	1060 ± 100	1420 ± 360	21.0	—	153 ± 36	—
Pd_{10} (*)	10+5p	25.2	0.2262	1100 ± 160	—	10.0	—	67 ± 15	—
Ep_1	?	1.3	0.0256	1150 ± 300	970 ± 300	20.0	0.97 ± .03	197 ± 13	μ
Ep_2	13+18p	4.95	0.0700	900 ± 75	860 ± 105	0.16	0.85 ± .2	—	—
Ep_3	9+2p	6.04	0.0820	1015 ± 85	1090 ± 130	few grains		—	—
Ep_4	6+1p	9.0	0.1068	910 ± 70	890 ± 90	0.85	1.0 ± .1	—	—
Ep_5	?	1.52	0.0290	800 ± 250	1070 ± 220	0.2	1	—	—
Ep_6	?	1.4	0.0286	960 ± 220	825 ± 180	3.4	0.975 ± .05	290 ± 60	—
Ep_8 (*)	28+6p	9.5	0.1068	980 ± 150	920 ± 155	—	1	—	—
				862 ± 60 (o)					
Ep_9 (*)	2+0p	2.05	0.0368	950 ± 250	1210 ± 390	—	1	—	—
Ep_{10} (*)	11+2p	8.7	0.1034	990 ± 150	1100 ± 200	—	1	—	—
				920 ± 60 (o)					
Ep_{11} (*)	29+11p	2.7	0.0442	950 ± 140	1083 ± 294	—	1	—	—
Ep_{12} (*)	13+5p	37.4	0.2954	960 ± 130	850 ± 180	—	1	—	—
Ep_{13} (*)	?	19.3	0.1880	880 ± 80 (o)	1420 ± 310	7.18	1.03 ± .03	200 ± 20	—
				960 ± 130					
Ep_{14} (*)	?	9.63	0.1152	1240 ± 90 (o)	934 ± 165	23.205	$E = 33.3$ MeV		μ
				1300 ± 175					
				1050 ± 90 (+)					
Ep_{15} (*)	21+0p	4.66	0.0684	—	1005 ± 320	—	1	—	—
Ep_{16} (*)	8+2p	27.8	0.2384	—	1075 ± 190	—	0.96 ± .09	—	—
Ep_{17} (*)	3+6p	14.0	0.1462	steep		49	1.05 ± .02	180 ± 10	—
Ep_{18} (*)	?	10.3	0.1152	—	1195 ± 260	—	1	—	—
Ep_{19} (*)	4+0n	0.585	0.0153	—	—	—	1.14 ± .11	—	—
Ep_{20} (*)	?	18.0	0.1746	steep		—	1	—	—
Ep_{21} (*)	?	40.0	0.3064	—	1120 ± 160	20	0.98 ± .02	194 ± 34	—
Ep_{22} (*)	7+0n	29.5	0.2384	—	1230 ± 240	5	1.16 ± .15	195 ± 30	—
Ep_{23} (*)	19+1p	18.4	0.1814	—	1060 ± 200	—	—	—	—
Rc_1 (*)	16+0n	7.54	0.0930	—	660 ± 210	—	steep	—	—
Rc_2 (*)	25+15n	23.8	0.2138	—	1020 ± 300	—	steep	—	—

(*) Stripped emulsions. (°) Measured by photometric method. (+) Grain Count.

ABLE I (*continued*).

	Primary					Secondary			
K Particle	Parent star	Range (mm)	Time of flight (in10^{-9}s)	Mass in m_e (g, R)	Mass in m_e (α, R)	Length (mm)	g^*	$p\beta$ MeV/c	Mass (m_e)
Rc_3 (*)	8+0n	49.5	0.3582	—	850 ± 125	—	$1.02 \pm .06$	steep	—
Rc_4 (*)	6+3p	3.6	0.0558	—	1060 ± 260	—	steep	—	—
Rc_5 (*)	?	31.8	0.2618	—	950 ± 220	—	—	—	—
Rc_6 (*)	9+4	40	0.3064	--	1030 ± 160	—	steep	—	—
Rc_7 (*)	?	20.2	.01880	980 ± 130	—	14.6	$E = 28$ MeV		μ
Ro_1 (*)	16+8n	12.1	0.1310	1020 ± 65	1040^{+280}_{-140}	π^--meson: $E = 38.5$ MeV (3-prong σ-star)			—
Ro_2 (*)	?	> 24.6	0.2138	935 ± 40	steep	29.0	(°)	(°°)	—
Ro_3 (*)	14+6n	20.2	.01880	860 ± 35 980 ± 60	1020^{+150}_{-120}	18	$1.07 \pm .06$	230 ± 30	—
Ro_4 (*)	6+0p	35.7	0.2844	950 ± 50 1000 ± 40 980 ± 330†	720^{+120}_{-90}	4.83	$E = 13.6 \pm .3$ MeV		μ

(*) Stripped emulsions.
(†) By (α, g).
(°) 1.24 ± 0.07 at decay point. 1.36 ± 0.08 after 29 mm.
(°°) $E_\pi = 103 \pm 7$. $E_\mu = 83 \pm 5$.

The mean value of the Mass is

$$1005 \pm 11 \ m_e .$$

The mean value of all determinations involving the method of ionisation v. range is

$$985 \pm 14 \ m_e ,$$

and the mean value for the method of scattering v. range is

$$1050 \pm 20 \ m_e .$$

The mean of the photometric density measurements is

$$979 \pm 36 \ m_e .$$

These values have been further divided between results from glass-backed emulsions and stripped emulsions with the following results:

	Glass-backed	*Stripped*
ionisation v. range	$1010 \pm 40 \ m_e$	$980 \pm 15 \ m_e$
scattering v. range	$1060 \pm 30 \ m_e$	$1040 \pm 30 \ m_e$

It should be noted that the measurement by ionisation v. range tends to give significantly lower mass values than those by scattering v. range. The latter depend on the value of the scattering constant used by the various laboratories.

The difference is 65 ± 24 m_e, nearly three standard deviations (S.D.). There does not appear any significant difference between results obtained in glass-backed and those obtained in stripped emulsions. We shall therefore group together results from glass plates and stripped emulsions, but separate ionisation from scattering measurement v. range. The means are shown in Table II for the main groups of data coming from some of the principal laboratories. Most of these means are consistent within the experimental errors. Those inconsistencies which are observed may be due to the fact that the breaking down of an

TABLE II. – *Emulsion data on masses of K-particles.*

Group	Mass in m_e (α, R)		Mass in m_e (g, R)	
	Glass-backed	Stripped	Glass-backed	Stripped
Bo	—	936 ± 53	—	1021 ± 34
Br	1144 ± 60	1132 ± 106	1151 ± 84	1025 ± 40
BxGeMi	1105 ± 65	965 ± 65	1080 ± 125	—
It	1031 ± 105	—	1068 ± 130	—
Ko	—	1380 ± 104	—	1008 ± 39
Ep	944 ± 56	1086 ± 60	943 ± 43	1025 ± 58
Pd	—	981 ± 71	—	1000 ± 36
Rc	—	940 ± 80	—	980 ± 30
Ro	—	915 ± 100	—	920 ± 35

inhomogeneous group of particles into smaller samples may lead to fluctuations in the mean mass measurements. Furthermore, these samples may themselves differ because of the different conditions of exposure of the emulsions, for, as MENON has pointed out during discussion in this meeting, the creation of types of K-particles by different types of primaries, e.g. π-mesons or nucleons, may well result in fluctuation of the relative numbers of the various types of K-particles.

ii) *Tentative separation according to type of decay.* – We may now try to break down the distribution of mass values into the separate groups of K-particles suggested in section **1** by using the $p\beta$ and the mass values of the secondaries. It will be assumed firstly that there exist the K_μ and one other particle. The $p\beta$ primary-mass spectrum is continuous from 10 MeV/c to 320 MeV/c with a maximum at about 170 MeV/c. The following values are obtained:

a) Mean mass of all primary K-particles giving secondaries of $p\beta =$ $= 197 \pm 1$ S.D. MeV/c

ionisation v. range	1069 ± 84 m_e,
scattering v. range	1113 ± 60 m_e.

b) Mean mass of all primary K-particles giving secondaries with $p\beta >$ $> 197 \pm 1$ S.D.

ionisation v. range $914 \pm 30\ m_e$,
scattering v. range $1000 \pm 90\ m_e$.

c) Mean mass of all primary K-particles giving secondaries with $p\beta <$ $< 197 \pm 1$ S.D.

ionisation v. range $997 \pm 20\ m_e$,
scattering v. range $1012 \pm 44\ m_e$.

We observe that the masses of K-particles giving rise to secondaries with $p\beta$ in the neighbourhood of that proposed for the K_μ do not seem compatible with a unique mass of $920 \pm 20\ m_e$. For ionisation v. range the difference is $149 \pm 86\ m_e$. There must, therefore, be present another particle of higher mass giving secondaries in this range of $p\beta$; in fact, if the K_μ is defined as a particle giving a two-body decay into $\mu + \nu$ (or γ), it can account for less than 30% of the K-particles observed in emulsions.

If we now assume the existence of the K_π as distinct from the $\varkappa$-meson, and separate the mass values of the primaries on the basis of the measurements of mass of the secondaries we obtain:

Mass of K-particles giving secondaries of mass $\geqslant 273 \pm 1$ S.D. m_e

i.e. $M(K_\pi) = 955 \pm 44\ m_e$ ionisation v. range,
$995 \pm 65\ m_e$ scattering v. range.

Mass of K-particles giving secondaries of mass $\leqslant 214 \pm 1$ S.D. m_e

i.e. $M(\varkappa) = 1035 \pm 25\ m_e$ ionisation v. range,
$1110 \pm 84\ m_e$ scattering v. range.

The difference between the two is not significant. Given the uncertainty in the validity of mass discrimination by scattering-ionisation on the fast secondaries it is of interest to note that the mean mass of those K-particles giving rise to slow μ-mesons, whose identification is certain is:

$M(\varkappa) = 1030 \pm 30\ m_e$ ionisation v. range.

Adopted Mass Values. – If we accept provisionally as more reliable the mass determinations by ionisation-range we have the following mass values:

$$
\begin{aligned}
M(\varkappa) &= 1035 \pm 25\ m_e \\
M(K_\pi) &= 955 \pm 44\ m_e \\
M(K_\mu) &= 920 \pm 20\ m_e \\
\hline
M(K_L) &= 985 \pm 15\ m_e
\end{aligned}
$$

The differences between these values are so small, and the errors so large that no significant information can be deduced from them as to the relative frequencies of these groups of particles.

iv) *Evidence for* K-*particles of mass* $> 1000\ m_e$.

a) *High values of* $p\beta$. Since the maximum value $p\beta$ can assume for a particle of mass 966 m_e (decaying to a π-meson) is 200 MeV/c, higher values of $p\beta$ should indicate a higher primary mass. It may be noted from Table I that *no* new cases of high $p\beta$-values have been found since the Bagnères Conference. A few cases were noted at Bagnères but all had large errors [10].

b) *High values of* p. One very good example has been found by the Jungfraujoch group [11] in which a charged K-meson decays to a particle of $p = 250 \pm 20$ MeV/c, at an angle of $117 \pm 2^{\circ}$ with the primary. The minimum mass of the primary is $1250 \pm 80\ m_e$.

c) *High mass measurements.* Several of these have been reported at this Conference, for example, the Paris $\varkappa$-meson, three methods giving a mean mass value for the $\varkappa$-meson of $1170 \pm 65\ m_e$. On the other hand an equally precise measurement by the Rome group of a meson which decays to a slow μ-meson gives a mean mass value for the $\varkappa$-meson of $975 \pm 30\ m_e$ [12]:

d) *Anomalous* K^0-*decays.* K^0-mesons which decay to particles of mass 1000 m_e must necessarily have high mass values (see **1** (vii)).

Ionisation - Scattering measurements on fast particles. – DANIEL *et al.* observed a group of particles of mean mass 1200 m_e [13]. Later more recent measurements by FOWLER and PERKINS [14] seem to indicate that this group is in reality composed of a group of particles of mass about 1000 m_e and another of mass 1450 m_e. The authors are very reserved about these particles, since although the measurements were made on tracks of high quality the results are subject to the incertainties of the method of determination of mass by ionisation-scattering.

The Rehovoth group [15] find also a group of particles of mean mass of the order of 1300 m_e but state that their statistics do not permit them to distinguish two groups such as those reported by the Bristol group. None of these particles has been observed to decay, but two appear to show nuclear interactions.

4. – Lifetimes.

i) θ^0-*meson.* – The best value of the lifetime of this particle is probably still the one given in the Bagnères Report, namely $\tau = (1.7^{+2}_{-0.6}) \cdot 10^{-10}$ s. The assumption is made that the V_2^0-particles are mainly θ^0-mesons.

ii) *Charged* K-*mesons*. – The data from the cloud chamber are relevant if it is assumed that charged V-particles are largely K-mesons. Hyperons have been observed among charged V-particles, but their number is probably small.

The value of the lifetime found by ASTBURY *et al.* [16] was $\tau(V^-) \geqslant 4 \cdot 10^{-9}$ s. ARMENTEROS *et al.* [17] suggest that charged V-particles contain at least two groups of particles, the K_μ with lifetime $> 5 \cdot 10^{-9}$ s and charged V-particles with much shorter lifetimes. ARMENTEROS *et al.* have given as the order of magnitude of the lifetime of the K_μ and the $\tau \sim 10^{-8}$ s and of the other K-particles $\sim 10^{-9}$ s.

YORK *et al.* [18], with a system of two normal cloud chambers separated by a metal plate, observe in the upper chamber V-particles of mean life

$$5 \cdot 10^{-10} < \tau(V) < 2 \cdot 10^{-8} \text{ s}$$

undergoing three-body decay, and in the lower chamber a group of mean life

$$10^{-11} < \tau(V) < 3 \cdot 10^{-10} \text{ s} .$$

The latter seem to have a two-body decay scheme. They suggest that the longer-lived group might be identified with the $\varkappa$-meson and the shorter-lived group composed eventually of χ-mesons and hyperons.

MEZZETTI and KEUFFEL [19] have made a direct counter determination of the lifetime of a mixed group of K-mesons, excluding π-decays, μ-decays, τ-decays, and K-decays which result in the emission of low momentum secondary particles. They obtain a value of $9 \cdot 10^{-9}$ s.

5. – Charge Asymmetry.

The Paris group finds a marked positive excess among the S-particles stopped in their lower chamber. They suggest [17] that this group consists of particles of long life and that there is another shorter lived group with charge symmetry. There is some evidence for a positive excess among the τ-mesons, since 7 of the 10 possible τ-decays in flight observed in cloud chamber are positive, and only 3 negative. YORK *et al.* [18] find a strong positive excess among the short lived V-particles and charge symmetry for those of longer life.

There is little information on the sign of the K-particles from the emulsion work. What we do know in this field can be summarized as follows:

a) The τ-meson. At least 80% of the τ-mesons decays observed in emulsions must be positive. This does not tell us anything however about the

presence or absence of the negative counterpart since it might be captured and interact with the nucleus, thus contributing to the class K; (see below).

b) K-particles. The small number of σK-particles observed with respect to the number of K-decays indicates either a strong positive excess among the K-particles or a weak interaction, and the decay of the negative K-particle.

c) This latter information, imprecise as it must be when based on relative frequencies derived from direct scanning is supplemented by the first results from the method of following out grey tracks from stars, while measuring their mass. This has led to the identification of 7 K-particles of which one left the emulsion before being brought to rest and of the other 6 all decayed. No σK has yet been found in these experiments.

6. – K-interactions at rest (σK).

In Table III are given details of 16 events in which a nuclear disintegration is produced by a particle of mass intermediate between the L-meson and the proton, at the end of its range. The interactions can be classified into three main groups:

a) Stars consisting of evaporation particles only: 4 cases.
b) Stars in which a charged L-meson is produced with or without evaporation particles: 7 cases.
c) Stars in which a hyperon is produced: 1 case.

It may be noted that, in general, the release of energy is small. π-mesons have been definitely identified in several cases. The range of energies of the π-mesons is 27-54 MeV. High-energy protons are produced in 4 cases. Because of the shortness of the primaries, cases K-Bo_1 and K-Bo_2 cannot be identified with certainty as K-particles, and in two other cases the errors of measurement are so large that the identification cannot be considered certain. The Rome particle K-Ro_1 (see the Report on τ-mesons, Table VI, pag. 432 of this issue) is assumed to be a σK-particle and not a decaying K^--particle for the data given above. It is not included in Table III.

7. – ρK-events.

The Lund group has reported the observation of three K-particles which stop in the emulsion without producing any visible products [20].

TABLE III. – *Nuclear interactions produced by K-particles at rest* σ(K).

σK Particle	Parent Star	Range (μ)	Primary: Mass in m_e (g, R)	Primary: Mass in m_e (α, R)	Star particles: Identity	Star particles: Energy (MeV)
Bo_1	14+2n	308	—	1000^{+740}_{-400}	p p π	1.0 0.5 28.1 $\pm$0.8
Bo_2	25+5n	92	—	—	p p p π	7.8 0.5 4.2 29.2 $\pm$0.9
Bo_3	4+6n	25 000	975 $\pm$100	1015 $\pm$120	p p p p or d p	7.8 2.1 4.1 > 17 > 180
Bo_4	?	29 260	1320 $\pm$100	850 $\pm$95	p p	8.1 9.0
Bo_5	?	1 200	—	540^{+290}_{-170}	p p	6.5 > 120
$GeMi_1$	10+2n	10 640	—	1170 $\pm$230	Very slow particle Y decaying in flight	$\sim$ 1 $\sim$ 60
$GeMi_2$	7+4p	41 000	—	970 $\pm$90	p p slow electron	6.7 18.3
Bh_1	?	3 600	1050 $\pm$150	1200 $\pm$300	t or π slow electron	—
Ko_4	11 $\pm$4p	21 000	—	880 $\pm$250	2 short black tracks 1 track at minimum ionisation	—
Lu_4	2+1n	1 820	985 $\pm$70 (photo-metric)	—	p probable π leaves emulsion after a few μ	22
Mn_1	—	1 620	1000 $\pm$150 (G, R)	1 900 $\pm$500 photometric	π p	54 $\pm$10 15

TABLE III (*continued*).

σK Particle	Parent Star	Range (μ)	Primary: Mass in m_e (g, R)	Primary: Mass in m_e (α, R)	Star particles: Identity	Star particles: Energy (MeV)
Mn_2	—	1560	$\sim$ proton (G, R)	1260 ± 400	p p p	1 1 7.5
Pd_1	$6+1p$	11140	—	1070 ± 160	p p π recoil	42 17 37
Pd_2	$9+1n$	41000	—	985 ± 150	p p	13 11
Pd_3	$5+1n$	75000	—	987 ± 120	p p p	7 90 45
Pes_1	?	16150	—	1745 ± 100	π^+ (gives μ-decay) electron track track with g^* between 1 and 1.5	27 ± 1 ~ 2

8. – K-interactions in flight.

Apart from the two examples of fast K-particles quoted above, one slow K-particle has been observed to lose 30 MeV energy in a large angle scattering before coming to rest and decaying (Rochester group) [21].

9. – Production of K-mesons.

There is evidence from the Brookhaven experiments [22] that K-mesons can be produced together with hyperons in a process of the type

$$\pi + N \to Y + K ;$$

the importance of this process in the production of K-mesons observed in

emulsions is not yet established. The Bombay group [23] has observed one event in which a meson and a hyperon are emitted from the same star and another in which the associated particles are an interacting particle (K or hyperon) and a decaying K-particle. One event consistent with this process has also been observed at Bristol.

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Report of the Committee on Charged Hyperons.

P. ASTBURY, A. BONETTI, M. CECCARELLI, N. DALLAPORTA,
C. FRANZINETTI, M. FRIEDLANDER and G. TOMASINI

1. – Introduction.

Both in papers already published, and others presented at this conference, evidence has been given which confirms the existence of unstable charged particles of mass greater than that of the proton. In our discussion, the results from photographic emulsions and expansion chambers will be treated separately.

In emulsions, 33 examples of charged hyperons have been reported.

We classify them as follows:

	at rest	in flight
a) Particles decaying to a light secondary . . .	5	14
b) Particles decaying to a proton	2	5
c) Non-decaying and non-interacting fast particles .	–	4

Data on production, mass, time of flight and decay or interaction of these particles are collected in Tables I and II.

Two examples of non decaying and non-interacting fast particles of hyperprotonic mass have also been reported (1 from Washington [1]), and 1 from the Bristol group [2]). These observations are not discussed here.

2. – Experimental Results. Photographic Emulsions.

2·1. *Production*. – Of 30 examples, 23 have origins inside the emulsion. Fig. 1 shows the distribution of energies of the primary stars, estimated from

(1) D. T. KING, N. SEEMAN and M. M. SHAPIRO: *Phys. Rev.*, **9**, 838 (1953).
(2) P. H. FOWLER and D. H. PERKINS: see in this issue, pag. 236.

the number of visible tracks. The energy appears to vary from 0.5 to 40 GeV per nucleon; most of the hyperons come from stars of energy lower than 8 GeV/nucleon.

From one star (Y-Bo_1) a τ-meson and a hyperon have been observed to emerge, and from another (Y-Br_4) a K-meson and a hyperon. In one example (Y-Ro_1) the hyperon appears in the emulsion associated with no other visible track. In one event (Y-$GeMi_2$) the hyperon is produced by the interaction of a σK.

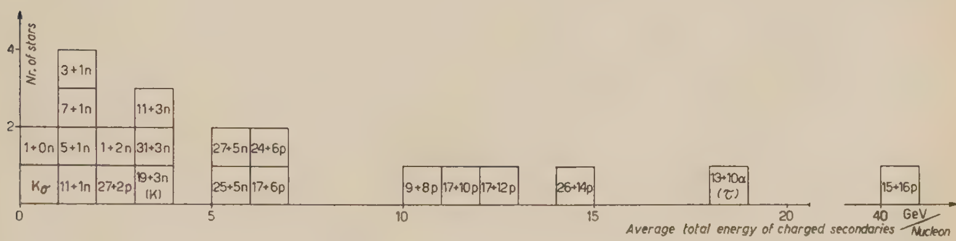

Fig. 1.

2·2. *Mass Measurements.* – In Fig. 2 are plotted the direct mass measurements on the primary particles. Because of the different techniques employed, and possible systematic differences between laboratories, it is not considered significant to calculate a mean mass, nor can any conclusions be drawn yet as to the existence of a unique mass or of more than one hyperon mass.

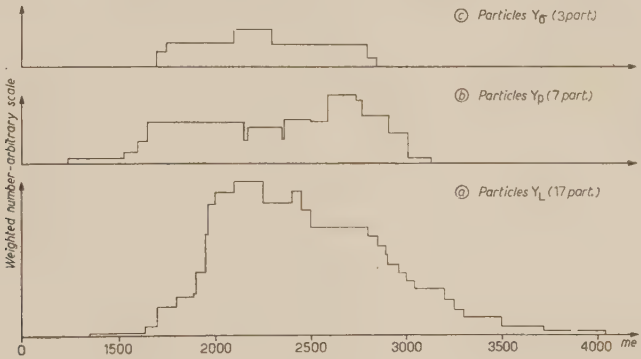

Fig. 2.

These measurements have been made by scattering-range, grain density-range, gaps vs. range and grain density-scattering.

2·3. *Measurements on secondaries.* – In a number of cases, the observations on grain density and scattering show that the secondary particle is certainly a light meson, probably a π-meson, but no such secondary has yet been ob-

TABLE

Particle	Reference	L (mm)	n	β_e	β_d	M (m_e)	t, (s)	T_r	Parent star
				PRIMARY					
Y-Bo$_1$	Bagnères Conference *Phys. Rev.*, 92, 438 (1953)	19	strip.		$p\beta$ (decay) 118 ± 5 MeV/c	2200^{+600}_{-400} (α, R) 2500 ± 380 (G, R)	$2.08\cdot10^{-10}$	∞	13+1 (τ)
Y-Bo$_2$	» »	8			(in flight)	2460 ± 500 (α, g)		∞	17+
Y-Bo$_3$	» »	5.4			» »	2610^{+300}_{-250} (α, g)			24+
Y-Bo$_4$	» »	24			» »	2775 ± 185 (α, g)			17+
Y-Bo$_5$	» »	4.22			» »	2470 ± 300 (α, g)			1+2
Y-Br$_1$	Padua Meeting (1954) *Phil. Mag.* (April 1954)	4.72	1 strip.		0.26 ± 0.01	2750 ± 500	$5.8\cdot10^{-11}$		26+1
Y-Br$_4$	Padua Meeting (1954)	4.4	strip.		0.6 ± 0.2	2500 ± 500	$\sim1\cdot10^{-11}$		9+8
Y-Br$_3$	» »	15	1		(I/I_0 = = 1.9)	2200 ± 300			15+
Y-Br$_5$	» »	9			0.54 ± 0.02	2300 ± 350	$4\cdot10^{-11}$		19+3 (K)
Y-GeMi$_1$	*Nuovo Cimento*, **10**, 345 (1953)	15.76	2		(at rest)	2210 + 250 (α, R)	$2.14\cdot10^{-10}$	∞	
Y-GeMi$_2$	Bagnères Conference *Nuovo Cimento*, **10**, 1736 (1953)	1.25	1		»	2340 ± 700 (α, R)	$3.45\cdot10^{-11}$	∞	
Y-GeMi$_3$	» »	0.9	1		»	2300 ± 800 (α, R)	$2.72\cdot10^{-11}$	∞	

ons (For the symbols used see pag. 459).

SECONDARY												
n)	n	θ	$p\beta$ (MeV/c)	E (MeV)	β_e	β_e^*	p_t (MeV/c)	p^* (MeV/c)	I/I_0	M (m_e)	Q (MeV)	Remarks
t			160 ± 13	103 ± 9					1.26	330 ± 60	135 ±35	
72									1.25 ±0.1		110 ±25	
450 ds)										1 950 p	129 ±11	
24 ds)										p	225 ±25	
6 ds)										»	212 ±22	
13	11 strip.	145°5	85 ± 5 from I/I_0		0.68 ±0.01	0.78 ±0.01	72 ± 2	176 ± 6	1.34 ±0.02		100 ±6	calculated from I/I_0
late tal cm	8 strip.	28°4	160 ± 20						0.98 ±0.5		36 ± 10	
ate	16								1.15 ±0.05		65 ± 20	
late		46°	180 min.value for π						~1		>85	
12	1								~1			
25									~1			
70				$18.7\pm.2$					(ends)	2030^{+530}_{-480} (α, R) 1840 ± 670 (g, R) p	115 ± 3	

TABLE I (*continued*).

Particle	Reference	PRIMARY							
		L (mm)	n	β_e	β_d	M (m_e)	t_r (s)	T_r	Par sta
Y-GeMi$_1$	Padua Meeting (1954)	0.6	1		(in flight)				3 +
Y-GeMi$_5$	» »	5.82	6 strip.		(at rest)	$2\,300 \pm 600$	$1 \cdot 10^{-10}$	∞	27 –
Y-GeMi$_6$	» »	0.6	1 strip.	0.31 ± 0.02	0.31 ± 0.02	2700 ± 1350 (α, g)	$7 \cdot 10^{-12}$	∞	K$^-$-
Y-GeMi$_7$	» »	4.14	2 strip.	0.23 ± 0.02	0.19 ± 0.02	$2\,700 \pm 600$ (α, g)	$5.6 \cdot 10^{-11}$	∞	7 –
Y-It$_1$	» »	0.8		0.20	0.20	$2\,500 \pm 900$	$1.4 \cdot 10^{-11}$		
Y-Pd$_1$	Bagnères Conference *Nuovo Cimento*, **10**, 1207 (1953)	3.25	1		0.23	$2\,100 \pm 400$	$4.6 \cdot 10^{-11}$		11+
Y-Pd$_2$	Padua Meeting (1954)	0.95	1 strip.		(at rest)	1 840	$2.9 \cdot 10^{-11}$	∞	5+
Y-Pd$_3$	» »	15	8 strip.		0.371 ± 0.007	1900 ± 250	$1.4 \cdot 10^{-10}$		11+
Y-Rc$_1$	» »	1.8	1 strip.	0.29	0.29	$2\,390 \pm 500$ (α, g)	$2.1 \cdot 10^{-11}$		25+
Y-Ro$_1$	» »	4.29	0 strip.	0.219	(at rest)	$1\,840 \pm 500$ (α, R) $3\,000 \pm 500$ (G, R)	$0.79 \cdot 10^{-10}$	∞	1+
Y-Ro$_2$	» »	31.97	22 strip.	0.4	0.17	3 400 $2\,100 \pm 150$ (G, R)	$3 \cdot 10^{-10}$		>
Y-Ws$_1$	*Phys. Rev.*, **92**, 838 (1953)	3.7			(at rest)	$2\,860 \pm 860$	$0.74 \cdot 10^{-10}$	∞	
Y-Ww$_1$	Padua Meeting (1954)	2.9			0.33	$1\,900^{+450}_{-300}$	$2.9 \cdot 10^{-11}$		17+

						SECONDARY						
L (mm)	n	θ	$p\beta$ (MeV/c)	E (MeV)	β_e	β_e^*	p_t (MeV/c)	p^* (MeV/c)	I/I_0	M (m_e)	Q (MeV)	Remarks
0.1	1								~ 1			
'/plate									~ 1			
'plate	7	32°	204 ± 21 (α)	133	0.86	0.77	126	167 ± 20	1.07 ± 0.02		95 ± 21	calculate from $p\beta$
2/plate	5	23°	166 ± 17 (α)	104	0.82	0.75	79	160 ± 20	1.1 ± 0.02		90 ± 20	
0.9		90° ± 1		53 ± 20					1.6 ± 0.1	300 ± 75	72 ± 20	
4.3	1	14°		70						286 ± 30	131 ± 24	
1.68 ends)				18.5 ± 0.3						$2\,200^{+600}_{-400}$ p	116 ± 2	
28.7 ends)	10	26°		97.7 ± 1.2						p	125 ± 30	
7/plate		43°13′	195 ± 30 (I/I_0)	132 ± 30	0.855 $\pm .013$	0.806 $\pm .013$	155 ± 3	191 ± 35	1.015 ± 0.05		116 ± 50	calculate from I/I
12	1 strip.		> 50						~ 1			
7.2	7	55°	170 ± 30		0.821 ± 0.04				1.25 ± 0.08			
2.2			150 ± 35							330 ± 90	114 ± 32	
3		22°	186 ± 30	122						$2\,000^{+450}_{-300}$ p	146 ± 40	

TABLE II – *Star produ*

σY Particle	Reference	PRIMARY						
		L (mm)	n	β_e	β_d	M (m_e)	t_r (s)	Pare sta
Br_2	Padua Meeting (1954) *Phil. Mag.* (April 1954)	4.64			(at rest)	$2\,680 \pm 350$ (α, R) $2\,200 \pm 350$ (G, R)	$9 \cdot 10^{-11}$ $8.7 \cdot 10^{-11}$	31 +
Du_1	*Phil. Mag:* (April 1954)	7.35	3		»	$2\,280^{+700}_{-480}$ (α, R) $2\,100^{+600}_{-800}$ (G, R)	$1.2 \cdot 10^{-10}$	$\sim$3 sur
Pd_4	Padua Meeting (1954)	9.43			»	$2\,150 \pm 300$	$1.5 \cdot 10^{-10}$	27 +

served to come to rest in the emulsion. In other events, the secondary has come to the end of its range, and can be identified as a proton. No other types of charged secondaries have been observed in emulsions.

2·4. *Modes of decay and Q-values.* – It has been assumed that the observed particles, when they do not interact, decay according to the scheme:

$$Y_L^{\pm} \to \pi^{\pm} + n + Q \tag{1}$$

or alternatively

$$Y_P^{+} \to p + \pi^0 + Q\,. \tag{2}$$

From a knowledge of the momentum and the mass of the particles concerned in the decay the Q can be calculated. Of the 26 showing decay, only for 18 cases the Q value was reported and measurements of the secondaries were available.

11 of these cases show decay into an L-meson (in a few cases the secondary could be also a lighter particle). 8 of these may be well interpreted according to scheme (1) and are all consistent with a unique value of $Q = 110 \pm 10$ MeV.

The three other cases with L secondary appear to be inconsistent with

…yperons. (For the symbols used see pag. 459).

	Secondary Star				
…rong No.	Prong Length	Prong Identity	Prong Energy (MeV)	Total visible Energy (MeV)	Remarks
1	13.2 mm	p	100 ± 15	100 ± 15	
2	*a)* 4 μ *b)* 2 mm	*a)* p *b)* p	(~ 1) (~ 20)	~ 21	
3	*a)* > 11 mm *b)* ~ 1 μ *c)* ~ 1 μ	*a)* p *b)* ? *c)* ?	~ 60	~ 60	

the above Q-value. The Q-values are:

$$\mathrm{Br}_2 \quad 36 \pm 10 \text{ Mev}, \qquad \mathrm{It}_1 \quad 72 \pm 20 \text{ Mev}, \qquad \mathrm{Br}_3 \quad 65 \pm 20 \text{ Mev}.$$

It cannot be excluded that the neutral particle is a Λ^0-particle. This will scarcely affect the Q-values.

The large spread in the Q-value of Y_L-events could of course be explained with a three-body decay.

Seven cases decay into a proton. Following scheme (2), 5 are consistent with a unique value of $Q = 116 \pm 2$ MeV: the two remaining cases seem to correspond to a much higher Q-value:

$$\mathrm{Bo}_5 \quad 212 \pm 22 \text{ Mev}, \qquad \mathrm{Bo}_6 \quad 225 \pm 25 \text{ MeV}.$$

On the other hand, of the 5 cases decaying in flight, two (Ww_1 and Pd_3) show a definite *decrease* in grain density after a sharp deflection, which provides a certain indication that the event is not simply a scattering.

The other three examples (Bo_4, Bo_5, and Bo_6) show on the contrary *increase* in ionisation after the deflection and therefore could be consistent either with a decay in flight, or with a nuclear scattering or interaction, as it is pointed out by the authors themselves. The Bristol group has several events similar to those of Bombay, but has not yet completed their analysis.

For all such apparent possible decays, it will be necessary to calculate the apparent Q-value, and show that there is a peak in the distribution (if the decay is only a two body decay).

The Q values corresponding to the two assumed decay schemes are plotted in the histogram of Fig. 3.

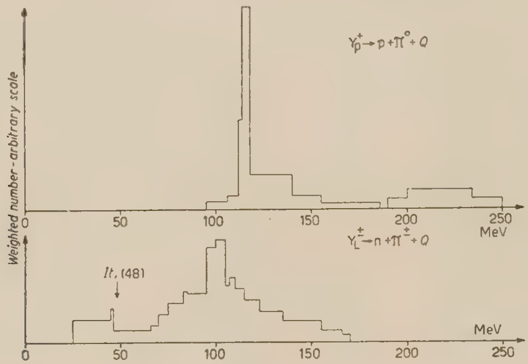

Fig. 3.

2·5. *Lifetime*. – An estimate of the lifetime of hyperons has been made by the Rome group (see this issue), using a modification of Bartlett's method, on 10 events.

The value given, $\tau = 2.9^{+4.8}_{-1.1} \cdot 10^{-10}$ s, is to be considered rather above the real value. The apparent lifetime is increased due to different detection efficiencies for fast and slow particles. Informations from other experiments cannot be added as the essential parameter T_r has not been reported. The estimate of the lifetime given above relies on the assumption that all the observations are on one type of particle.

On the other hand, should the charged hyperons consist of a mixture of particles with different lifetimes, then considerably more data and some means of separating the hyperons are needed before a lifetime calculation can give a significant value.

2·6. *Nuclear interaction*. – Three events have been reported in which a hyperon is observed to come to the end of its range, and there produce a small star. In all cases, the visible energy release is not higher than 100 MeV.

In none of these, there is a π-meson amongst the secondaries.

A particles of mass $1\,745 \pm 100\ m_e$ interacting at rest with a nucleus of the emulsion has been described by the Paris École Normale group (see this issue, pag. 280). It is interpreted as a σK but it could also be a σY.

Finally, a number of short or very short tracks interconnecting two stars, which have been reported by several authors as possible examples of K-part-

icles or unstable fragments, can as well represent nuclear interactions of slow charged hyperons.

2·7. *Relative frequency.* – In view of the unsystematic way in which Y's have been found, nothing can be said.

3. – Cloud Chamber Evidence.

3·1. There are 5 examples found in cloud chamber of a charged V decay which appear to yield as a neutral secondary a V^0-particle (cascade process):

1 from Manchester (Physical Laboratory, University; see *Nature*, **167**, (1951), pag. 501).

3 from Pasadena (California Institute of Technology; see *Proceedings of Bagnères Conference*, 1953, pag. 99.)

1 from Paris (École Polytechnique; see in this issue, pag. 327.)

In one case (Paris) the plane defined by the V^0-decay contains the apex of the charged V-decay but not the source of the shower which was the origin of the charged V-particle. There is no indication of momentum unbalance about the line of flight of the V^-.

In all the 5 events the primary charged V-particle is negative.

In all the 5 events the angle made by the line of flight of the V^0-particle to the direction of the primary V^- is less than 4° and is much smaller than the angle made by the charged secondary. This indicates that the mass of the neutral particle is greater than that of the charged secondary. In one case (Pasadena) the V^0 can be identified as a Λ^0-decay. In another case (Paris) the charged secondary can be identified as a π-meson. All the five events are consistent with

$$Y^- \to \Lambda^0 + \pi^- + Q\,.$$

In one case (Pasadena) the estimated Q is 67 ± 18 MeV (standard deviation) and in another (Manchester) is in the range $15 < Q < 60$.

3·2. – Two events (Pasadena) can be interpreted as

$$Y^+ \to p + \pi^0 + Q\,.$$

They have p_t values of 125 ± 25 MeV/c and 160 ± 40 MeV/c.

3·3. – The Brookhaven Cosmotron group have observed two events which can be interpreted as the decays of Y^- particles produced by 1.5 GeV π^--mesons.

In one case the assumed Y^--particle may be produced in the reaction.

$$\pi^0 + p \to Y^- + K^+ .$$

In the other case, for a decay into a neutron and a π^-, the Q-value is 130^{+25}_{-15} MeV.

4. – Conclusions.

The conclusions can be summarized as follows:

a) The masses of 30 out of 33 examples observed in photographic emulsions show that at least one charged unstable particle exists with hyperprotonic mass.

b) 13 cases can be interpreted according to the scheme

$$Y_1^\pm \to \pi^\pm + n + Q \quad (8 \text{ cases}) \tag{1}$$

or alternatively

$$Y_1^+ \to \pi_0 + p + Q \quad (5 \text{ cases}) \tag{2}$$

which give Q-values (110 ± 10 MeV for the first and 116 ± 2 MeV for the second) which are consistent with a unique mass of the primary of $2327 \pm 3\ m_e$ obtained from the two Y_p-decays at rest. If it is assumed that it is the same particle that decays in two different ways, the Q-value of the second reaction should be about 6 MeV higher than that of the first. One case of artificially produced negative Y is consistent with the first decay scheme.

c) The evidence of the « cascade decay » from cloud chamber work may be interpreted with the assumption of a particle (until now known only in its negative charged state) with a mass of about $2570\ m_e$, which decays according to the scheme:

$$Y_2^- \to \pi^- + \Lambda^0 + \sim 60 \text{ MeV} \tag{3}$$

and which may provisionally be indicated by Y_2 to avoid confusion with the preceding Y_1. Moreover the light secondary could equally well be a μ-meson. It may be remarked that including the well known neutral hyperon Λ^0 of mass $2180\ m_e$, there are up to now three different possible types of hyperons Λ^0, Y_1, Y_2.

d) We may try to explain the anomalous Q-values observed in plates without introducing any new type of hyperon:

I) The low value 36 could represent the decay of a possible charged counterpart $\Lambda^\pm$ of the Λ^0 according to the scheme:

$$\Lambda^\pm \to \pi^\pm + \mathrm{n} + \sim 37 \text{ MeV}.$$

II) The lower Q-values could be considered as the emulsion evidence of the Y_2-decay according to scheme (3).

III) Finally if the two Bombay events with very high Q-values are to be interpreted as decays, they could perhaps be explained as the decay of the positively charged counterpart of particle Y_2 with the same mass of about 2 570 according to the scheme:

$$Y_2^+ \to \pi^0 + \mathrm{p} + \sim 230 \text{ MeV}.$$

e) The spread in the Q-values of the Y_L-events could be explained with the assumption of a three-body decay: $Y \to L + ? + ? + Q$.

f) In some cases, hyperons and K-mesons are associated in their production and interaction; cf. stars with ejected hyperons and K- or τ-meson; hyperon from K^--stars; and Brookhaven evidence. It cannot yet be said whether this is always the case, and whether one of the hyperon K-meson pair may not in some cases be uncharged.

g) The mean lifetime of the charged hyperons is very probably less than $5 \cdot 10^{-10}$ s.

h) Hyperons have been observed to come to rest and interact. The energy release in such interactions is very much less than the rest mass energy of the hyperon.

5. – Standardization of the Results.

It has been found rather difficult to compare and discuss the results from different laboratories because in many cases insufficient information was available about the observed examples. The committee has therefore compiled a list of data which should be supplied whenever an event of this type is found and published:

Primary particle	*Secondary*
Origin	θ Angle to primary (if it decays in flight)
β_e Velocity at emission	β_e Velocity of emission in the laboratory system (L.S.).

Primary Particle		*Secondary*	
β_d	Velocity at decay	β^*_e	Velocity of emission in the center of mass system) (C.M.S.)
L	Length observed (mm)	$(p\beta)_e$	momentum times velocity in the laboratory system
n	No. of plates crossed	p^*_e	Momentum in the center of mass system
M	Mass measurements	E	Kinetic energy in the laboratory system
t_r	Observed time of flight	p_t	Transverse momentum in the laboratory system
T_r	Available time of flight (1)	M	Mass measured or identity
		L	Length (total or per plate)
		n	No. of plates crossed
		Q	Energy release with given decay scheme
		I/I_0	Ionization relative to minimum

Most of these data refer both to nuclear emulsion and cloud chamber techniques. For the other data which are requested in nuclear emulsion techniques, see the recommendations of the Bureau of Standards; the method of search should be noted.

(1) C. Castagnoli, G. Cortini and C. Franzinetti: *Observations on Charged Unstable Particles Heavier than Protons (Hyperons)*, see in this issue, p. 297.

Report of the Committee on Neutral V's.

C. CASTAGNOLI, M. FRIEDLANDER, M. MERLIN and M. TEUCHER

All V_1^0-events studied up to today in nuclear emulsions, are shown in Tables I and II, according to whether they were observed in normal or stripped emulsions.

In both cases the events are assumed to be due to the disintegration into two bodies (π and p) of a neutral particle in flight, and on that basis the Q-value has been calculated.

In Fig. 1 all the Q-values so obtained have been plotted, by the method of constant area. The hatched portions refer to events found in ordinary emulsions (Table I).

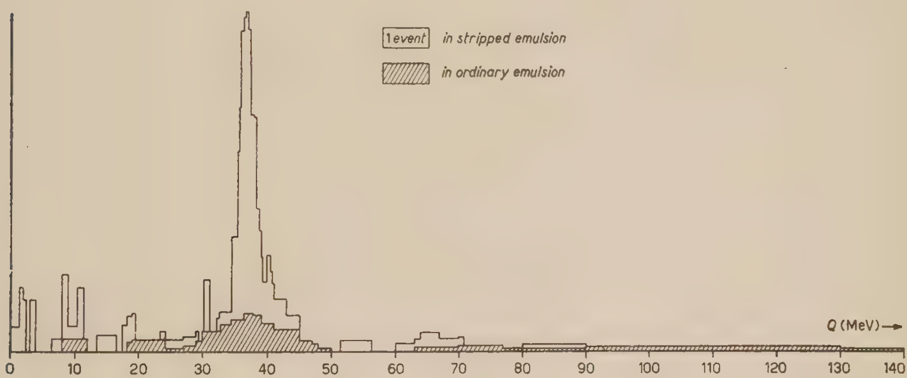

Fig. 1.

The graph shows one clear peak corresponding to a Q-value 37 MeV evidently due to the decay of the Λ^0. All the remainder of the graph (at least as far as things stand at present) can be considered as a background of two-prong stars due to neutrons.

TABLE I. – V_1^0 *in ordinary plates.*

V_1^0 Particle	π^- R (μ)	π^- E (MeV)	p R (end.) (μ)	p R (calc.) (μ)	p E (MeV)	φ	Q (MeV)	Notes
Be_1		25			46	133°	40 ± 5	*Proc. Bagnères Conf.*, 1953.
Br_1						123°.5	43 ± 5	*Proc. Bagnères Conf.*, 1953.
Br_2						126°.7	41 ± 4	*Phil. Mag.*, April 1954.
Br_3						137°	37 ± 4	» » » »
Br_4						134°.6	70 ± 8	» » » »
Br_5						45°	10 ± 2	» » » »
Mlb_1		215 ± 30			62 ± 20	40°	130	*Phys. Rev.*, **80**, 1099 (1950).
Mi_1	3994	14	6190		40.1	170°.3	34 ± 4	*Proc. Bagnères Conf.*, 1953.
Ro_1		34^{+11}_{-7}	192		5.36	96°	29 ± 13	*Nuovo Cim.*, **9**, 1351 (1953).
Ro_2		$38.5^{+13.5}_{-8.2}$		560	$10^{+4}_{-2.5}$	97°	35^{+14}_{-8}	» » »
Ro_3	1180	6.2		10500	62^{+20}_{-12}	120°	$20.4^{+3.8}_{-2.3}$	» » »
Ro_4		18.6^{+6}_{-5}	> 260			117°	> 20	» » »
Ro_5		$47.5^{+12.5}_{-8.5}$	684		10.8	84°	40^{+11}_{-7}	» » »
Ro_6		$35^{+9.5}_{-6.5}$		2800	$25.5^{+4.5}_{-3.5}$	90°	34^{+10}_{-5}	» » »
Ro_7		31^{+29}_{-20}	193		5.36	93°	108^{+25}_{-13}	» » »
Ro_3		88^{+47}_{-23}	99		3.5	140°	92^{+40}_{-33}	» » »

TABLE II. – V_1^0 *in stripped emulsions.*

V_1^0 Particle	π^- R (μ)	π^- E (MeV)	p R (end.) (μ)	p R (calc.) (μ)	p E (MeV)	φ	Q (MeV)	Notes
Bo_1	725	5.22			118	170°	37 ± 2	*Proc. Bagnères Conf.*, 1953
Bo_2	5284	16.5			42	168°.5	38 ± 3	» »
Bo_3	5140	16.1			90	121°.2	40 ± 5	» »
Bo_4	9170	67.5		(deuter.)	62	131°	84 ± 10	» »
Br_1	250	2.76		4400	32.4	20°.7	0.5	*Phil. Mag.*, May 1954.
Br_2	23700	39.40		114000	216	28°.6	8.3	» » » »
Br_3	10910	24.60	3990		30.7	64°.0	18.3	» » » »
Br_4	4830	15.21			310	50°.0	26.2	» » » »
Br_5	6290	17.79	9200		49.5	130°.2	35.6 ± 0.6	» » » »
Br_6	6110	17.58	7740		44.8	140°.7	36.6 ± 0.7	» » » »
Br_7	7190	19.22	14490		64.4	116°.4	36.6 ± 0.5	» » » »
Br_8	4900	15.40	10050		52.1	146°.8	36.8 ± 0.6	» » » »
Br_9	3070	11.74	13940		63.0	167°.1	36.9 ± 0.5	» » » »
Br_{10}	2340	10.40	23420		85.0	148°.1	37.2 ± 0.5	» » » »
Br_{11}	18050	33.43	147		4.52	159°.0	37.4 ± 0.9	» » » »
Br_{12}	8820	21.70		48000	129.5	85°.4	37.4 ± 1.2	» » » »
Br_{13}	19870	35.43	313		7.15	126°.4	38.1 ± 0.9	» » » »
Br_{14}	42060	55.70	294		6.89	42°.2	38.1 ± 1.0	» » » »
Br_1	25600	41.28	22210		82.5	79°.8	41.4	» » » »
Br_{16}	5530	16.21		112000	215	87°.4	42.6	» » » »
Br_{17}	65800	73.01		60000	147	65°.5	54.1	» » » »
Br_{18}	36500	51.10		24000	84.2	97°	63.3	» » » »

TABLE II (*continued*).

V_1^0 Particle	π^- R (μ)	π^- E (MeV)	p R (end.) (μ)	p R (calc.) (μ)	p E (MeV)	φ	Q (MeV)	Notes
Br_{19}	9500	22.70		47000	127	143°.5	67.7	*Phil. Mag.*, May 1954.
Br_{20}	14000	28.61		102000	203	128°.4	85	» » » »
Pd_1	26800	43.0	6150		40.2	69°	34.5 ± 2	Padua Meeting, 1954.
Pd_2	2830	11.3	1890		20.1	103°	14.9 ± 1.5	» » »
Pd_3	24100	39.7	2800		25.3	93°	39.2 ± 1.5	» » »
Pd_4	6100	17.9	12900		61.2	130°	38.8 ± 2	» » »
Rc_1	14600	29.8	2620		24.5	116°.7	37.8 ± 0.6	
Rc_2	1605	8.3	838		12.6	27°.3	3.2 ± 0.4	
Rc_3	1525	8.1	2820		25.4	77°.3	8.3 ± 0.3	
Rc_4	925	6.05	458		9.2	151°.7	10.9 ± 0.3	
Rc_5	2982	11.84	5877		38.4	23°	2.2 ± 0.3	
Rc_6	10046	24.0	746		11.6	138°.7	30.7 ± 0.5	

For a more exact determination of the Q-value of the Λ^0 we have held to the value given by FRIEDLANDER *et al.*, since the events found by them constitute the majority of cases with both branches ending in the emulsion. Further this group has made a special study of the various causes of experimental error, such as the original thicknesses of the emulsions and their humidity at the time of the experiment; the stopping power of the emulsion under such conditions, and the best range-energy relation applicable. The Q-value so obtained is 36.92 ± 0.22 MeV and the mass of the Λ^0 2181 ± 1 m_e (taking $m_p = 1836.13\ m_e$ and $m_\pi = 272.5\ m_e$).

The Q-values obtained with the Wilson cloud-chamber, and in particular by the Massachusetts Institute of Technology and Indiana groups, are in good agreement with the above value; however, the value given by the Princeton and Manchester groups are somewhat higher.

It is difficult to comment on the frequency of the Λ^0's occuring in the emulsions, due to the different methods of searching adopted by various laboratories (following back π^-, two prong stars) and also due to the diversity of the exposures.

Nervertheless in following back π-mesons with stripped emulsions of the Sardinian expedition of the 1953 the frequency of the Λ^0's are the following:

1 Λ^0 for ~ 40 σ created and brought to rest in the stack (Bristol);
1 Λ^0 for ~ 50 σ created and brought to rest in the stack (Padua);
1 Λ^0 for 1500 stars of at least three prongs (Padua).

Events of type $\pi^- + \pi^+$ are shown in Table III.

TABLE III. – V^0-*Events both tracks being* π.

V^0 Particle	π^-			π^+			φ	Q (MeV)	Notes
	R (end.) (μ)	R (calc.) (μ)	E (MeV)	R (end.) (μ)	R (calc.) (μ)	E (MeV)			
Bo_1			360	2640		11	69°	132 ± 17	*Proc. Bagnères Conf.*, 1953.
Br_1	3128	12.2 ± 0.2				342 ± 26		202 ± 11	*Phil. Mag.*, **45**, 413 (1954)
Mi_1	1836		8.3			840 ± 120	23°	210 ± 35	Padua Meeting, 1954.

For the 2 cases with $Q \sim 200$ MeV (Bristol and Milan) there is reason to believe that these are due to the decay in flight of the θ^0-particle.

Report of the Committee on Unstable Fragments.

M. GRILLI and R. LEVI SETTI

1. – A total of 17 events which have been reported as delayed disintegration of unstable charged fragments has been observed so far and the relevant data are collected in Table I in which complete bibliography is also given.

In those events in which the track of the supposed fragment is very short (less than 20-30 μ) their identification is uncertain. They might be equally well interpreted as σY or σK captures or even the good old π^-, σ-stars. Such events are marked * in the Table.

The possibility of an alternative explanation in terms of a σK capture or delayed disintegration of a helium fragment has been outlined by LAL *et al.* [1] for an event in which the track was 92 μ.

The real number of cases is therefore probably smaller than suggested by the Table.

Three amongst the definite examples show the emission of a π-meson from their spontaneous disintegrations, in only one case it was possible to identify it as a π^--meson from the σ-capture at the end of its range.

In the remaining cases the presence of a light meson amongst the disintegration products seems to be excluded.

2. – In none of the cases the total energy release in the disintegration of the fragments is inconsistent with the hypothesis, first suggested by M. DANYSZ and J. PNIEWSKI [2], that a neutron in the fragment is simply replaced by a Λ^0. One case (Göttingen event) in which the energy release seems to be higher than allowed could also be interpreted with another disintegration scheme giving an energy release which could be much lower.

This observation does not exclude of course that other interpretations of the delayed disintegrations of fragments are possible.

An event has been reported by LAL *et al.* [3] which could be interpreted

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as the disintegration of an excited « dineutron » into a π^--meson and a deuteron, with a Q of 89 ± 10 MeV. It might be the first example of a charged hyperon bound to one nucleon [4], its interpretation is not however unambiguous, as it might well be interpreted as a 2 prong star.

3. – The lifetime of all the fragments identified with certitude exceeds 10^{-12} s, in one case is greater than $3 \cdot 10^{-10}$ s.

The fragments seem to have all decayed at rest or at least very near to the end of their ranges, except in the case reported by the Lund group, in which the fragment possibly decayed at a certain residual range. It is however rather difficult to detect a decay in flight of a fragment of relatively high charge at short residual ranges and, on the other hand, it is difficult to distinguish a decay in flight of a low charge fragment from a nuclear interaction.

4. – Fig. 1 shows a plot of the frequency of occurrence of unstable fragments against their charge, Z. The shaded area corresponds to the « meson emitting » fragments; they appear in the low charge region. The plot also indicates that fragments with Z greater than 2 seem to be more frequent. For comparison, Fig. 1 also contains the frequency-charge distribution of stable fragments emitted in nuclear disintegration with $N_h \geqslant 7$; only deuterons and tritons are included in the plot for $Z = 1$. Stable and unstable fragments belong to a comparable energy interval. The proportion of stable fragments with charge > 2 is exceedingly small with respect to that of deuterons, tritons and α-particles.

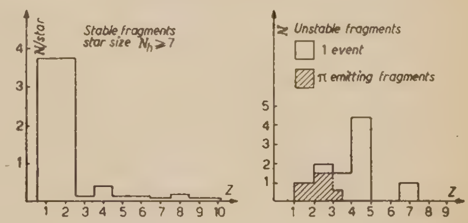

Fig. 1.

One should therefore expect, in average, to observe a much greater number of unstable fragments of charge 1 and 2 than is found.

This conclusion, being based on a distribution which is subject to the considerable uncertainty in the determination of the charge of the fragments, must be considered as only tentative. The attribution of a charge to an unstable fragment of short range can be relied upon only when supported by the charge balance of the decay products.

5. – As has been pointed out by the Padua group at this Meeting, a considerable percentage of the protons produced in the disintegration of the fragments have rather high energies.

Six protons of energy > 30 MeV have been observed in the more definite 10 cases not accompanied by π-emission and 3 of them have energies greater

TABLE I.

Parent star	Range (μ)	Z	Time of flight (s)	DISINTEGRATION PRODUCTS Identity and Energy (MeV)				Q (MeV)	Disintegration scheme	Notes and References
				1	2	3	4			
$22+3n$	13 000	1	$3\cdot10^{-10}$	π^- (σ_5) 39.4 ± 1.0	^{3}He (from charge-conservation) 2.7 ± 0.6			41.7 ± 1.0	$^3H^*\to{}^3He+\pi^-+Q$	Particles 1 and 2 collinear. $\Delta=5.1\pm1.1$ MeV B_n (binding energy of neutron) $=6$ MeV BONETTI *et al.*: *Nuovo Cimento*, **11**, 210 (1954)
6 prongs primary: π^- of 1.5 GeV	260	2	10^{-11}	π (from (g, R), (g, α)) 26.0 ± 0.7	p 5.3	^{3}He (from charge conserv.) 3.5		35 ± 0.8	$^4He^*\to{}^3He+ +p+\pi^-+Q$	Particles 1, 2, 3 coplanar. $\Delta\sim18.0$ MeV $B_n\sim20$ MeV HILL *et al.*: *Bull. Am. Phys. Soc.*, **29**, 60 (1954).
$31+14p$	190	1-2-3	$>10^{-11}$	p (prob.) 93	d (prob.) 17			140–180 150–185 140	$^3He^*\to p+p+n+Q$ $^4He^*\to p+d+n+Q$ $^4He^*\to \to p+p+2n+Q$	CIOK, DANYSZ and GIERULA (Warsaw): private communication
$30+30p$	68	2-3	$>4\cdot10^{-12}$	π (g, α) 25^{+4}_{-3}	p 2.7	recoil (1.4 μ)		29 ± 4 28 ± 4	$^7Li^*\to{}^6Li+ +p+\pi^-+Q$ $^4He^*\to{}^3He+ +p+\pi^-+Q$	$\Delta=-1\pm4$MeV $B_n\sim7$ MeV $\Delta=12\pm4$MeV $B_n\sim20$ MeV CRUSSARD *et al.*: *Compt. Rend. Ac. Sc.*, **236**, 64 (1953)
$16+0p$	219	2-3	$>10^{-11}$	p (prob.) 48 ± 3	p-d-t-α 4 (p)	p-d-t-α 1.6 (p)				TIDMAN *et al.*: *Phil. Mag.*, **44**, 350 (1953).
$18+14n$	80	3-4	$>4\cdot10^{-12}$	p (prob.) 40	p-d-t-α 3.1 (p)	p-d-t-α 1 (p)		>80		CIOK, DANYSZ and GIERULA: *Nuovo Cimento*, **11**, 436 (1954)
$10+7p$	170 ± 5	4	$5.2\cdot10^{-12}$	p (prob.)	p (prob.)	p	p			1, 2, 3, 4 not coplanar. Padua group (Padua Meet-

									$+2p+3n+Q$	balance. Rochester group (Padua Meeting)
17+5?	55	4	$3\cdot10^{-12}$	α 39	α 43			170 ± 3 176 ± 3	$^{8}Be^{*}\rightarrow{}^{3}He+{}^{4}He+n+Q$ $^{9}Be^{*}\rightarrow{}^{4}He+{}^{4}He+Q$	$\Delta=15\pm5$ MeV $B_n=19$ MeV $\Delta=2{,}7\pm5$ MeV $B_n=1.7$ MeV FRY and WHITE: *Nuovo Cimento*, **11**, 551 (1954).
27+4p	262	4	$0.8\cdot10^{-11}$	α 12	α 14			195 >120	$^{9}Be^{*}\rightarrow{}^{4}He+{}^{4}He+n+Q$ $^{9}Be^{*}\rightarrow{}^{4}He+{}^{3}He+2n+Q$	Göttingen group (Padua Meeting).
21+18p	90	4-6	$>3\cdot10^{-12}$	p (prob.) 82	p-d-t-α 4.1 (p)	p-d-t-α 0.8 (p)	p-d-t-α (2.5 μ)	>130		DANYSZ and PNIEWSKI: *Phil. Mag.*, **44**, 348 (1953)
24+10p	30	4-7	$2\cdot10^{-12}$ (assumed) $^{14}_{7}N^{*}$	p (assum.) 125	p-d-t 5.2 (p)	$^{12}_{5}B$ 10.4		149 ± 11	$^{14}_{7}N^{*}\rightarrow p+p+{}^{12}_{5}B$	1, 2, 3 coplanar ($4°\pm5°$). $\Delta=10\pm11$ MeV $B_n=\sim10$ MeV FREIER *et al.* (Private communication)
out	1 400	9	$\sim2\cdot10^{-11}$	α 32	p (assum.) 10-15	$Z>2$ 4-5 μ				The fragment disintegrates 5-10 μ before stopping. Lund group: private communication
13+1n	2			p (assum.) 23.6	p (assum.) >5.4	p (assum.) 5	p (ass.) >6.5		(*)	LOVERA *et al.*: *Nuovo Cimento*, **10**, 986 (1953).
18+1p	13			p (prob.) 30	p (prob.) 3.8				(*)	CIOK, DANYSZ, GIERULA. *Nuovo Cimento*, **11**, 436 (1954).
11+1p	9 ± 2		$1.4\cdot10^{-12}$ (assumed) $^{7}_{3}Li^{*}$	p 32.5	d 21.5	p 11.7			(*)	1, 2, 3 are not coplanar. Padua group (Padua Meeting).
12+5p	~5			short	short	p (assum.) >25	p (ass.) ~25		(*)	LADU e MARONGIU: private communication.

than 80 MeV. If one likes to speculate on the mechanism of disintegration of the fragments which are not accompanied by the emission of charged mesons, it can be of interest to compare these data with those derived from the stars generated by σ-capture of negative π-mesons in light nuclei.

The proportion of fast protons for these stars is much lower: about 5 protons of $E > 30$ MeV/100 stars and 3 protons of $E > 80$ MeV/1200 stars.

6. – In 5 cases in which an estimate of the Q-value was possible from momentum balance and energy conservation, the quantity

$$\Delta = \sum_i m_i + Q - M - (m_{\Lambda^0} - M_n)\,,$$

has been evaluated on the assumption that a neutron of the fragment was replaced by a Λ^0. In this relation:

m_i is the mass of the i-th decay product;

M is the mass of the stable nucleus with same A and Z as the fragment;

m_{Λ^0} is the mass of the Λ^0;

M_n is the mass of the neutron.

As can be seen from the notes in Table I, Δ is positive in some cases, giving indication for some excitation of the fragment exceeding that corresponding to the mass difference $m_{\Lambda^0} - M_n$.

If it is assumed that the bound Λ^0 has the same Q-value as the free Λ^0 and Δ is regarded as the difference between the binding energy (B_n) of the neutron and that (B_{Λ^0}) of the Λ^0, it can be deduced that in 4 of the above mentioned cases the binding energy of the Λ^0 was smaller than that of a neutron. They give respectively:

$Z=1$	$B_{\Lambda^0} =$	1 ± 1	MeV	against	$B_n =$	6	MeV	(BONETTI *et al.*)
$Z=2$	»	2 ± 1	»	»	»	20	»	(HILL *et al.*)
$Z=2\text{-}3$	»	$\begin{cases} 8 \pm 4 \\ 8 \pm 4 \end{cases}$	»	»	»	7 20	»	(CRUSSARD *et al.*; 2 possible interp.)
$Z=4$	»	$\begin{cases} 4 \pm 5 \\ -1 \pm 5 \end{cases}$	»	»	»	19 1,7	»	(FRY *et al.*; 2 poss. interpretations)
$Z=7$	»	20 ± 11	»	»	»	10	»	(FREIER *et al.*)

Note added in proofs.

Following a suggestion of DANYSZ [5], referring to Fig. 1, the N *versus* Z distribution of unstable fragments is better compared with the $N \cdot (A - Z)$ *versus* Z distribution of stable fragments. These two distributions are in satisfactory agreement.

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Report of the Committee on Jets.

U. HABER-SCHAIM, F. T. HOANG, L. SCARSI and M. TEUCHER

The following evidence has been presented at the conference:

a) *Production on heavy mesons in jets of* 100 GeV *per nucleon.*

LAL, PAL and RAMA (Bombay) reported (see in this issue, pag. 239): $N_{\pi^0}/N_s = 0.40 \pm 0.04$. This gives an upper limit of 18% for heavy mesons among the shower particles.

b) *Interaction Mean Free Path.*

In the same paper of the Bombay group all published interactions of shower particles are summarized. Following a total path length of 909 cm 32 interactions were found. HOANG reported 92 cm with 4 interactions, TEUCHER 138 cm with 4 interactions, altogether 1139 cm with 40 interactions. This yields an interaction mean free path of 28.5 ± 4.5 cm very close to the geometrical mean free path.

c) *Very large showers.*

SCHEIN, HASKIN and GLASSER (Chicago) reported (see in this issue, pag. 355) two stars 32 + 127 n and 35 + 67 p and TEUCHER (see in this issue, pag. 361) one star produced by an ^{16}O nucleus of the type 29+221 F. The observed multiplicities seem to be higher than those predicted by the various theories.

Statistical evaluations of the jet data were presented by COLOMBINO, FERRONI and WATAGHIN, HOANG and HABER-SCHAIM (see in this issue, pag. 340, 342, 344). The commitee did not reach full agreement on the principles for statistical evaluations.

Due to the fact that the nature of a jet is still obscure and may include different types of phenomena and that its definition has depended on the particular scope of the investigation involved and therefore varied from laboratory to laboratory, this Commitee feels that to reach a clear understanding of the problem it will be extremely useful if all the information unused by the group

should be available to all workers in this field. For example, in this type of phenomena the bias due to scanning loss is very strong. Therefore to be useful these data should be completed by:

a) The ratio of $\mu \rightarrow e$ decays to ρ-mesons.

b) The density at the minimum.

c) The table of N_h versus N_s for all stars observed in the volume of emulsion explored.

As much as possible information should be given in the form of raw material. The Committee suggest that the following data should be always given:

a) Charge of the primary.

b) Number of black, grey and light tracks.

c) Angle of projection of light tracks, including primary, on the plane of the emulsion, with respect to the projection of an arbitrary axis (usually the vertical).

d) Dip angle of these tracks with respect to the plane of the emulsion, both uncorrected and corrected for shrinkage.

e) Plateau altitude of the balloon flight.

f) The charged primaries as well as all the jet particles should be followed and their length given as well as the secondary jets and interactions.

These recommandations are added to those given by the Bureau of Standards.

Whenever the nature of the publication does not allow inclusion of this information the tables containing it should be forwarded to the Secretary of the Bureau of Standards to be circulated.

Proposte di normalizzazione.

Recommendations for the Standardization of Measurements in Photographic Emulsions.

INTRODUCTION

The methods used at present for the measurements in photographic emulsions are the subject of detailed investigations that will undoubtedly improve their accuracy and reproducibility. Pending the results of these investigations, the use of standard methods of measurement is essential in the type of experiments carried out today, where results of many laboratories have to be combined.

For the purpose of establishing recommendations for standardized methods of measurement, discussions between specialists of different nations were held at the Varenna Summer School of 1953, and again at the Padova meeting of 1954.

The following persons took part in the discussions. Their names are listed in alphabetical order:

J. Ambrosen, A. Bonetti, G. Cortini, C. C. Dilworth, M. Friedlander, Y. Goldschmidt-Clermont, K. Gottstein, B. Gregory, D. Hirschberg, L. Jauneau, R. Levi Setti, E. Manaresi, A. Manfredini, M. Menon, M. Merlin, G. Mignone, D. Morellet, D. Moreno, G. Occhialini, C. O'Ceallaigh, Ch. Peyrou, C. F. Powell, G. Tomasini, G. Vanderhaeghe, L. Vigneron, C. Waddington, C. Waller and G. T. Zorn.

To enable the various groups to suggest improved methods as standards as they become available in the future, it is suggested that the laboratories using photographic emulsion technique should keep in close contact to exchange information on improvements in the methods of measurement.

It is agreed that all information will be centralized and distributed by a secretariat, organized by Y. Goldschmidt-Clermont of the European Council for Nuclear Research in Geneva.

It will be the task of this secretariat to centralize and to circulate information and suggestions received from the various groups.

RECOMMENDATIONS

1. – Use of the Standard Methods.

It is recommended that all publications include results obtained using the standard procedure described here. In addition, results obtained by other methods that may be preferred by individual groups can also be included in the same publications.

2. – Single Events.

Whenever a short description is given of a single or new event, it is recommended that all possible details of the observations made be included in the publication. The purpose of this is to enable other workers in the field to obtain an accurate picture of the event and of the significance of the observations. Details that might be mentioned are *for example*: the distance of track from cut or processed edges, the length by plate and the dip for various plates, information about the distorsion, depth, clarity of plate etc.

3. – Calibrations.

It is recommended that individual calibrations be always made. The use of calibrations from other laboratories or from other plates than those actually used in the measurements is strongly discouraged. The publications should always contain a detailed account of the calibrations made.

4. – Tables.

Dr. K. GOTTSTEIN has calculated tables of range, energy, β, momentum, $\sqrt{1-\beta^2}$, $p\beta$, time of flight for μ, π, τ, p and Y, which are included in the Proceedings of the Varenna School [1].

5. – Multiple Scattering Measurements.

a) *Calculation.* – The standard method for the measurement of scattering is based on the calculation of the arithmetic mean of the second differences obtained from non overlapping cells with a rigorous cut-off at four times the

mean. The cut-off procedure must be repeated until the final result is unchanged. The value of the mean angle of scattering thus obtained should always be given (see *f*)).

b) *Scattering Constant.* – The scattering « constant » corresponding to four times the cut-off should always be used whether there are second differences to be eliminated or not. The values based on Molière's theory are given by curve *b* reference [1] for 4 times cut-off. In the absence of any calibration measurements this curve should be used, but an additional error of 8% should be included in the finally quoted error. This additional error arises from the possible departure of the constant appropriate to the experimental conditions from that given by curve *b*, as appears to be indicated by the various calibration experiments that have been reported [2].

If the investigators have carried out calibration experiments on known particles under similar conditions, the constant obtained from these experiments may be employed. The value of the constant used and the errors of the calibration experiments should be clearly stated.

c) *Noise Elimination.* – The elimination of noise between the measurements at two different cell lengths is recommended. The smaller cell length should be taken such that the apparent scattering is due practically only to noise, the larger to give a scattering signal equal to four times the noise.

d) *Distorsion.* – The results of the measurements of multiple scattering should always include the values obtained without correction for distorsion. In order to obtain an idea of the magnitude of the distorsion, the methods of third differences either/and of cross products should be employed.

e) *Errors on Scattering Measurements.* – All errors quoted are standard deviations. The statistical error is taken as $0.75/\sqrt{N_2}$, where N_2 is the number of measurements on non-overlapping long cells. The error of the noise level is $(\varepsilon/D)^2\cdot(0.76)/\sqrt{N_1})$, where ε is the sagitta of noise, D is the second difference on the long cells and N_1 the number of measurements on non-overlapping short cells.

Systematic errors such as that introduced into the measurement by the curvature of the stage or distorsion of the emulsion must be taken into account.

f) *Consistency.* – It is suggested that the internal consistency of the measurement be checked by comparing the mean value of sections of the track, preferably in the various plates traversed. The magnitude of the fluctuations observed should be quoted. The number and magnitude of the second difference eliminated by the cut-off procedure should be indicated.

In the elimination of noise, if inconsistent results are obtained taking different combinations of cells, this should be indicated.

g) Constant Sagitta Method. [4, 5] – This method is recommended for the measurement of mass by scattering for particles which stop in the emulsion. The cell schemes contained in the tables of GOTTSTEIN should be used. There is some evidence that the statistical error resulting from the use of this method is larger there indicated in *e*).

6. – Ionisation Measurements.

a) The method of the mean gap length measurements (O'CEALLAIGH [6]) is recommended provisionally as the standard procedure, as it appears to be independent of the size of the grains. Further details on the use of this method and on the calibrations needed will be circulated by the secretariat. Since ionisation measurements are of comparison type, the calibration should be carried out using tracks with a similar value of ionisation at approximately the same depth in the same plate and in the « vicinity » of the event studied. The definition of « vicinity » must be given. Statements about the opacity of the plates and on the development gradient are requested.

b) For thin tracks, attention is drawn to the necessity of distinguishing between the ionisation plateau and the ionisation minimum. It is recommended to define explicitly the ratio of grain (or blob) density to plateau.

The term « minimum » is discouraged for tracks that « look very thin », the phrase « near minimum » should be used.

7. – Range Energy.

In the low energy region (up to 1 mm proton range), the curve of VIGNERON [7] or the equivalent table of GOTTSTEIN should be used.

It is recommended to determine the stopping power of the emulsion used from a measurement of the mean range R_μ of the μ-mesons from the decay of π-mesons. From this value of R_μ and using $E_\mu = 4.12$ MeV, the range-energy relation in the region 0.7 – 6 mm is normalized, and from the end points of the region, the normalization is extended to the other regions. Alternatively, the stopping power can be deduced from the density of the emulsion measured at the time of exposure.

The values of the constants given here refer to a Sardinian stack, which was found to have been exposed at about 55% relative humidity.

$0.7 \div 6$ mm:	$E = k_1 R^{0.568}$	$k_1 = 0.276$	These values of $k_{1,2,3,}$ refer to 55% humidity
$6 \div 50$ mm:	$E = k_1 R^{0.568}$		
$5 \div 25$ cm:	$E = k_2 R^{0.618}$	$k_2 = 0.1605$	
$0.6 \div 25$ cm:	$E = k_3 R^{0.589}$	$k_3 = 0.2303$	

In the region above 6 mm proton range, the energy is calculated by two relations, and the mean taken.

The high energy point used was measured by HEINZ [8]: 342.5 MeV protons; 92.68 ± 0.25 gm/cm^2, emulsion density 3.81 ± 0.01 gm/cm^3, emulsion C 2, humidity 55%.

The original emulsion thickness sholud either be measured at the time of exposure or deduced by the methods found for instance in [9] and [10].

Attention is drawn to the fact that emulsion thickness varies appreciably with atmospheric humidity before and after processing.

8. – Frequencies.

Scanning. – It is recommended that scanning methods be always indicated in order to obtain consistent evaluations of the frequencies of rare events.

Decaying Particles. – The frequencies of decaying particles found in normal scanning are subject to the visibility of minimum ionisation tracks. It is therefore recommended that in publications dealing with decaying particles found in this way the ratio of $\pi \to \mu \to e$ to $\pi \to \mu$ or $\mu \to e$ decays to ϱ observed in the same plates be given.

9. – Available Track Length.

In order to accumulate information for the determination of lifetimes and interaction lengths it is important to state the actual path length traversed by the particles before decay or interaction, and the path length it would have traversed in the stack before escaping if it had not suffered decay or interaction.

10. – Reported Events.

For the events already reported or published, it is suggested that the various groups should communicate to the secretariat, for circulation, the results obtained when an analysis is made using the standards adopted here.

11. – Masses.

When giving mass values, please indicate the values used for the masses of the π and μ-mesons.

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Report on the Expedition to Sardinia, 1953.

J. Davies

H. H. Wills Physical Laboratory - University of Bristol

C. Franzinetti

Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

1. – Introduction.

Following a suggestion made at the Bristol Conference on Heavy Mesons held in December 1951, a series of balloon ascents was made in the Mediterranean area in June and July 1952. The purpose of these flights was to expose nuclear research emulsions to the cosmic radiation at high altitude and low geomagnetic latitude for research groups from several European Universities. The balloons and equipment for these flights were contributed by the Universities of Bristol and Lund, where considerable experience had already been gained in obtaining flights of this nature. Teams for the launching of the balloons consisted of physicists and technicians drawn from the laboratories at Bristol, Brussels, Genoa, Lund, Rome, Padua, Milan, Göttingen, Turin and London (Imperial College). Because of the mountainous nature of much of the terrain in Southern Italy, and of the danger of spoiling plates through long exposure to the heat of the sun, it was planned to release the parachute and equipment over the sea. The services of a ship and aircraft to search for and recover the balloons, as well as facilities ashore, were made available to the Expedition by the Italian Navy and Airforce. As a launching base, Cagliari was chosen as being more suitable for the work of the Expedition than any other sea port in Southern Italy.

This expedition was only partly successful; the uncertain performance of the balloons was a contributory cause of the failure to recover many of the flights. Nevertheless, 1300 cm³ of emulsion were satisfactorily exposed and the experience helped to made the recent 1953 expedition a great success.

2. – The Sardinian Expedition 1953.

Immediately after the 1952 expedition it was suggested that another similar expedition should take place in 1953, and that in the time available some improvements in the organisation of the expedition could be made. It was agreed that contributions should be paid into a common fund and that the plates successfully exposed should be shared amongst the contributors, according to the amount of their contribution.

Early in 1953, the laboratories likely to be interested were circulated with details of the projected expedition which aimed at supplying the collaborating laboratories with a supply of nuclear research emulsions exposed for several hours at altitudes greater than 80 000 ft., and processed in a uniform manner. The initiative soon received the approval of many European laboratories while others joined at a later stage. The expedition eventually received the support of Research Groups from the Universities and Institutes listed below:

University of Bern
University of Bristol
Université Libre of Brussels
University of Caen
University of Catania
University of Copenhagen
University College, Dublin
Institute of Advanced Studies, Dublin
University of Genoa
Max-Planck Institut, Göttingen
Imperial College, London
University of Lund
University of Milan
University of Oslo
University of Padua
École Normale Supérieure, Paris
École Polytechnique, Paris
University of Rome
University of Sydney
University of Trondheim
University of Turin
University of Uppsala
University of Warsaw

This list includes Universities who where not advised beforehand of the forthcoming expedition but who bought emulsions not distributed at the Bern conference.

Arrangements had been made for the manufacture of some, if not all, of the balloons in Italy, together with the more delicate pieces of equipment such as clockwork releases and sand ballast releases. A plant for the balloon manufacture was set up at Padua where Dr. HEITLER of Bristol University supervised the work. At the Institute of Physics of Padua, a new type of machine for welding seams in the balloons was adopted. The machine was developed at the Institute of Electrical Engineering there, and though slower in operation than the hot air device used in Bristol, it is capable of sealing through several thicknesses of fabric. Balloon-making in Bristol continued; the two labor-

atories sharing the responsibility of producing between 20 and 30 balloons all capable of prolonged flight above 80000 ft. In addition, a few smaller polyethylene balloons were made for test purposes. A number of American neoprene balloons supplied by Göttingen enabled a comparison to be made between the two types of balloons.

The responsibility for the preparations of other parts of equipment as radio-winds, radio-sondes, sand releases, buoys, etc., was shared among several laboratories. Details giving the individual contribution in equipment and material are given in Table I.

TABLE I.

Bern	Bristol	Brussels	Göttingen	Milan	Padua	Rome
Nylon cord Processing Hydrogen	Balloons Radiosondes and receivers Parachutes and dye Escape tube valves Clockwork ballast releases Launching platform Nylon cord Adhesive tapes Processing	Processing	Rubber balloons Filling equipment	Buoys Plate containers	Balloons Escape tube valves Launching platform Nylon cord Processing	Clockwork cut-offs Radio cut-offs Ballast releases Filling equipment Hydrogen Fluorescein dye Radio-winds Batteries Processing Transport

Again this year the Italian Defence Ministry granted generous aid to the Expedition:

1) The services of the Italian Corvette « Pomona » (700 tons) for recovering the equipment from the sea. During the flights the « Pomona » complete 5150 sea miles in 476 hours of navigation. The ship was capable of about 14 knots and was specially fitted with radio-wind and radio-sonde receivers. The « Pomona » also carried about 50 tons of hydrogen cylinders and other equipment from Naples to Cagliari.

2) At Elmas Airport near Cagliari another radio-wind receiver was available together with a Bristol radio-sonde receiver. For visual observation several theodolites were loaned to the Expedition.

3) Adequate store room and workshop facilities were granted to the Expedition in addition to a lorry, a coach, and light van for the transport of personnel and equipment between Elmas and Cagliari.

4) The balloons could be inflated and tested under cover in a large aircraft hangar before being wheeled out into the open for launching.

5) A Cant/Z sea-plane, to search for the equipment in the sea.

6) First class Meteoreological information and advice was readily obtained.

7) The radio-wind instruments were continually manned for the duration of each flight by an Air Force Officer or senior N.C.O. The assistance of several Airmen was given when called for.

These facilities together with the local weather conditions of low rainfall, good visibility, light wind at dawn, helped to make Elmas an easy choice as a centre for the Expedition.

Arrangements were made for the plates to be flown from Ilford to Elmas via Rome in thermally insulated boxes. After exposure the plates were returned by air to Rome, Bristol or Padua where special arrangements had been made for the processing of large numbers of plates. Similar facilities were prepared and held in reserve at Bern. The fixing facilities of Brussels were transported to Padua.

Special thanks are due to Mr. WALLER of Ilford Ltd., for his cooperation in supplying at short notice the additional plates required by the Expedition and for speeding delivery by marking the plates with X-rays at Ilford.

3. – Technical Details of the Sardinian Expedition 1953.

3·1. *Equipment.* – In order to follow the progress of the flights and to improve the performance of the balloons, a quantity of auxiliary equipment was carried. The total load on each balloon varied from 25-35 kg, according to the weight of ballast carried, and the number of radio batteries. Of this load, only about 10 kg was contributed by the plates and their containers. Details of the equipment follow, together with a sketch showing the normal arrangement, or rigging of the apparatus (Fig. 1).

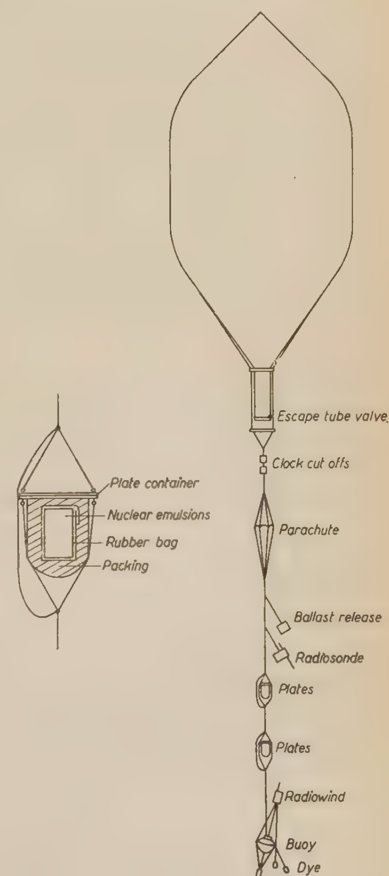

Fig. 1.

3·1.1. *Balloons.* – Table II gives some details of the balloons made for the Expedition. The first column headed « Balloon Size » gives the circumference of the balloon in the cylindrical centre section.

The balloons differed from those of the previous expedition in two respects: the hemispherical top was replaced by a cone of 45° semi-vertical angle. This decreased the tensions in the material at the top of the balloon during inflation, without altering appreciably the volume/weight ratio of the envelope. Secondly, a pressure controlled valve sealed off the bottom of the balloon until a height of about 60 000 ft was reached, when the sealing mechanism was jettisoned. This device prevented the intake of a large volume of air during

TABLE II.

Balloon Size	Length (inflated)	Weight	Volume	Attainable Altitude	
				No load	25 kg load
50 sect.	33 m	58 kg	4 000 m³	100 000 ft. 30 500 m	93 000 ft. 28 500 m
40 »	26 »	40 »	2 400 »	97 000 ft. 29 500 m	87 000 ft. 26 500 m
32 »	21 »	22 »	1 000 »	92 000 ft. 28 000 m	75 000 ft. 23 000 m
24 »	16 »	12 »	420 »	86 000 ft. 26 000 m	62 000 ft. 19 000 m

the early part of the ascent, and had the effect of bringing the floating altitude of the balloon very near to the theoretical height. In addition, two launching platforms of improved design were constructed, one at Padua, the other at Bristol.

The balloons were clamped to the platform, the strap passing just below the filling tube. The bottom two-thirds of the balloon was also supported on a tray attached to the platform. In this way the whole of the balloon, together with the equipment could be weighed before filling commenced. The accuracy of the weighing was $\pm$ 100 g. The balloon was then inflated until the balance point passed the original zero, and indicated a free lift of about 5 kg. Filling could be interrupted at any time to detect the presence of leaks in the envelope of the balloon.

3·1.2. *Clockwork Cut-Off Mechanism.* – On each flight two identical clockwork releases were normally set to operate within 15 to 30 minutes of one

another. Each consisted of a small alarm clock modified to close a switch connecting a small nichrome element to a 3 V battery. The element glowed, and melted the main nylon cord from which the parachute and equipment were suspended.

At one stage of the work, several consecutive failures of the releases were observed. The trouble was overcome by more thorough cleaning of the clocks immediately before the flight and re-aligning the escapement bearings which tendend to « bind » in some of them.

3·1.3. *Radio Controlled Cut-Off.* – The radio-controlled release designed and built at the University of Rome, was tried but operated successfully only on a short trial flight. The drawbacks of the design employed were

i) great weight (mainly battery weight);

ii) easily triggered during launching by knocks, and by misaligning the antennae;

iii) apparently short range and duration of the receiver.

A promising line of development in respect of such airborne radio control is the use of transistors in the receiving circuit, when these are reliable. Their use will also reduce the battery weight necessary for the radiosonde transmitters.

3·1.4. *Parachutes.* – The parachutes were of white silk, with a panel length of 2 m. With a 25 kg load, the velocity of descent at sea level would be about 200 m/min.

3·1.5. *Radio-sondes.* – The radio-sondes were designed and built at the University of Bristol, and operated at 70.5 MHz, with a range of about 300 miles. Two special receivers were brought for use with the instruments, which had been calibrated beforehand. The radio-sondes were capable of detecting very small changes (~ 30 m) in altitude, but the absolute accuracy was about 300 m. The transmitters had been soaked in a varnish which prevents corrosion in the sea. After washing and drying, those recovered by the ship continued to operate as before.

In some cases the calibration of these radio-sondes had altered during transport and storage, but additional altitude measurements obtained by direct theodolite observations from Elmas and Monte Serpeddì or Carloforte enabled corrections to be made.

3·1.6. *Buoys.* – Each balloon carried a buoy, the design of which is sketched in Fig. 2. The buoys, made in Milan, were both visual and radiomarkers for

the equipment after it had landed in the sea. They consisted of a water-tight box fitted with two tripods one on the top, two meters high, and the other below the box, carrying a counterweight about 1 m below the water surface to give stability. A radio-wind transmitter was fitted in a water-tight box on the top tripod and the batteries for this transmitter were carried within the buoy itself.

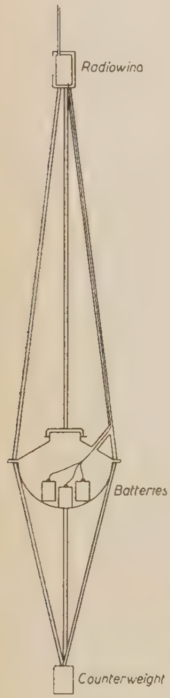

Fig. 2.

In order to facilitate its detection in the sea the buoy carried a red and yellow flag and several yellow bands and some mirrors were added to the top tripod. About 100-150 g of fluorescein sea marker dye were tied to the buoy. The buoy was attached to the main cord in such a way that the nylon did not foul the radio-wind antenna during the flight and the equipment following did not disturb the equilibrium of the buoy when it had landed in the sea.

3·1.7. *Radio-wind Transmitters.* – The radio-wind transmitters carried on the buoy were of the type often used for meteorological purposes, and were obtained through the Italian Airforce. Both the land and ship receivers were capable of detecting the signals up to a distance of about 140 km. With a power supply of three batteries (of the same type as those used for radio-sondes) they workedf or about 12 hours. These transmitters enabled the direction of the balloon to be found, and together with other measurements of height, supplied sufficient data for the position of the balloon to be determined.

The radio-wind signals were transmitted during the flight and also while the buoy was on the sea. These radio signals from the buoy confirmed the radio-sonde data that the equipment was descending and directed the ship towards to point of descent.

On several flights the radio-wind beacon was modulated by an Italian meteorological radiosonde which served as an additional check on the height of the balloon.

3·1.8. *Ballast Release.* – In order to prevent the balloon from gradually losing height due to small leaks and diffusion of hydrogen, some ballast release is desirable. Several sand ballast releases were made in Rome, according to a design previously employed in Bristol. The release of sand is controlled by an aneroid capsule, arranged so that sand is dropped as soon as the balloon loses altitude. This design however has now been shown to be too easily upset by shocks, and also to expend all the sand early on in the flight. In Sardinia a clock-controlled device was developed which released quanta of

sand at pre-set intervals. Fig. 3 illustrates the effect of this control; the arrows indicate the expected time of release of sand ballast.

At 80 000 ft the immediate increase in height resulting from the dropping of, say, 2 kg of sand was about 600 ft, as expected, but the balloon did not continue to rise until it reached its original ceiling. The release of sand did however temporarily check the descent of the balloon. The other advantages of this type of release are that it is simpler in design and manufacture, and more robust, capable in fact of withstanding the shocks of launching in all conditions.

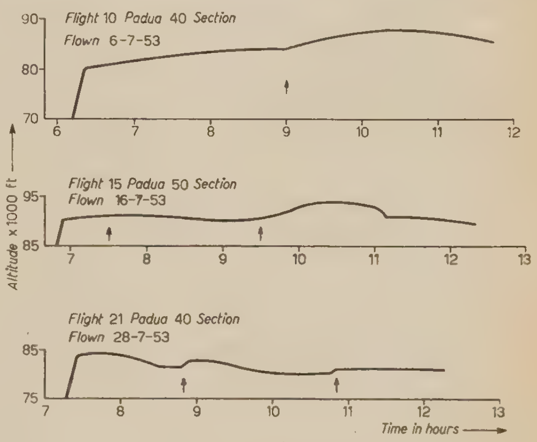

Fig. 3.

3·1.9. *Plates.* – The emulsions flown by the Expedition were Ilford G5, measuring 15 cm × 10 cm × 600 μ. Stacks were made up of 40 stripped emulsions and each packet of glass-backed emulsion contained a dozen plates.

The stripped emulsions were bound together between thick glass plates, wrapped and sealed and subsequently marked with X-rays at Ilford. They were then despatched by air to Rome, in thermally insulated boxes and redirected without delay to Elmas. Immediately after arrival, the plate packages were sealed in rubber bags, and packed into air-tight aluminium canisters with a light spongy material. The canisters were labelled and stored in a cool place, ready for their flight.

3·2. *Organisation.* – The Expedition personnel numbered 18-20, who remained in Sardinia for the whole period. About half this number had previous experience of balloon flying. The full complement of physicists and technicians arrived in Cagliari in the second week of June, but before this time a small group had completed arrangements and had launched a trial balloon, which was not a success. Bad weather had prevented further flying. Then between June 16th and July 30th, 21 flights were launched, a rate of 3 balloons a week. Unsuitable weather again prevented the completion of the programme and two balloons with the remaining plates were successfully flown and recovered from Padua.

A routine was established in order to make most effective use of the time available.

The decision to fly was made by a committee drawn from senior and experienced members of the expedition, following a weather forecast at 11.30 a.m. The commander of the « Pomona » was then immediately informed of this decision and, later in the day in the light of the most recent meteorological data, the probable trajectory of the balloon was mapped. As the « Pomonas »'s speed was 14 knots compared with 25-35 knots of the balloon at high altitude, the ship left port late at night, with three members of the expedition on board, in order to be in a convenient position along the track of the balloon next morning.

At 2 a.m. eight members of the launching team left the hotel for Elmas where they prepared the balloon and equipment in the hangar. First the balloon and equipment were placed on the launching platform and weighed. Then filling was started. Suspect seams in the envelope near the filling tube and the top of the balloon were carefully examined for leaks using a sensitive hydrogen detector. When any leaks had been repaired with adhesive tape filling continued until the lift was equal to the weight of the balloon and equipment plus the free lift of between $4\frac{1}{2}$ and $5\frac{1}{2}$ kg, depending upon the size of the balloon. The gas supply was disconnected, the filling tube tied off and the balloon left in the hangar. Any serious leaks remaining could easily be detected in a few minutes by means of the weighing attachment to the launching platform, but in fact none were found. When the light outside the hangar was sufficient the equipment was taken out of the hangar and the radio transmitters tested; the balloon was wheeled out attached to the cord and released. One person was responsible for each item of equipment during the launching.

Immediately after release the theodolites and radio receivers were manned continuously and the trajectory of the balloon plotted from observations of its height and bearings from Elmas using charts which had been specially prepared to facilitate the plotting. The ships officers were constantly informed of the balloon's progress and in turn transmitted to Elmas their observations upon it. Theodolite readings from other stations: Monte Serpeddì and Carloforte, were used to verify the radio-sonde data.

At 8 a.m. after the balloon had reached ceiling the first crew were relieved by the other members of the expedition who remained at Elmas while observations could be made on the balloon. An hour or so before the expected time of release of the equipment a sea-plane took off from Elmas to search for the equipment. The plane was in radio telephone contact with the ship and could direct the ship towards the equipment as soon as it had been spotted from the air. For most of the flights the ship was in a favourable position at the moment of release and on three occasions the fall of the parachute was observed and the equipment was seen landing in the water. On other occasions the radio-wind signals received on the ship enabled it to be directed towards the equipment without the assistance of the aircraft.

After recovering the equipment, the ship returned to port, or, if another flight was planned for the next day, the ship sailed towards the prearranged position along the course of the balloon ready for the next flight. The plates were stored in the refrigerator until the ship next returned to Cagliari.

3·3. *Remarks on Balloon Performance.* – As seen from the specimen charts, (Fig. 4, 5, 6, 7) the balloon's trajectories were remarkably similar in the successful flights. After passing through the ground winds, the ascending

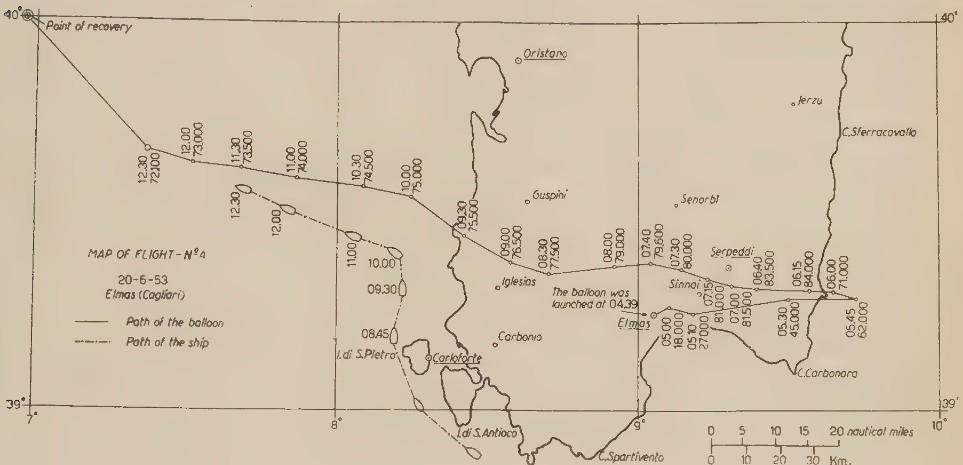

Fig. 4. – Map of a flight.

balloon was carried towards the east, the winds reaching a maximum speed of about 45 knots between 30 000 and 40 000 ft. At about 45 000 ft the winds were light and then they increased in strength, blowing from the east at between 25 and 35 knots. In the particular case of the rubber balloon flight at 106 000 ft., these upper easterly winds reached speeds of 45 knots.

As in 1952, it was observed that at an altitude of about 70 000 ft. the equipment frequently began to swing violently, through an arc of up to 60°. The balloon could be watched by theodolite, and also in great detail by means of a telescope loaned to the expedition by the Institute of Physics of the University of Cagliari. In one case, the balloon was seen to be torn while the oscillations were at maximum. In all other cases the balloon survived this critical period, and became steady at or near to its ceiling. The cause of these oscillations is believed to be due to some violent disturbance of the balloon in the upper air, but at present it is not possible to relate the occurrence of the oscillations with any particular weather conditions. It was originally thought that a large sail carried in the train of the equipment, to damp the pendulum motion, would be an advantage, but as the first balloon to burst carried a sail while following balloons without a sail continued to survive the oscillations, the sails were not afterwards included in the equipment.

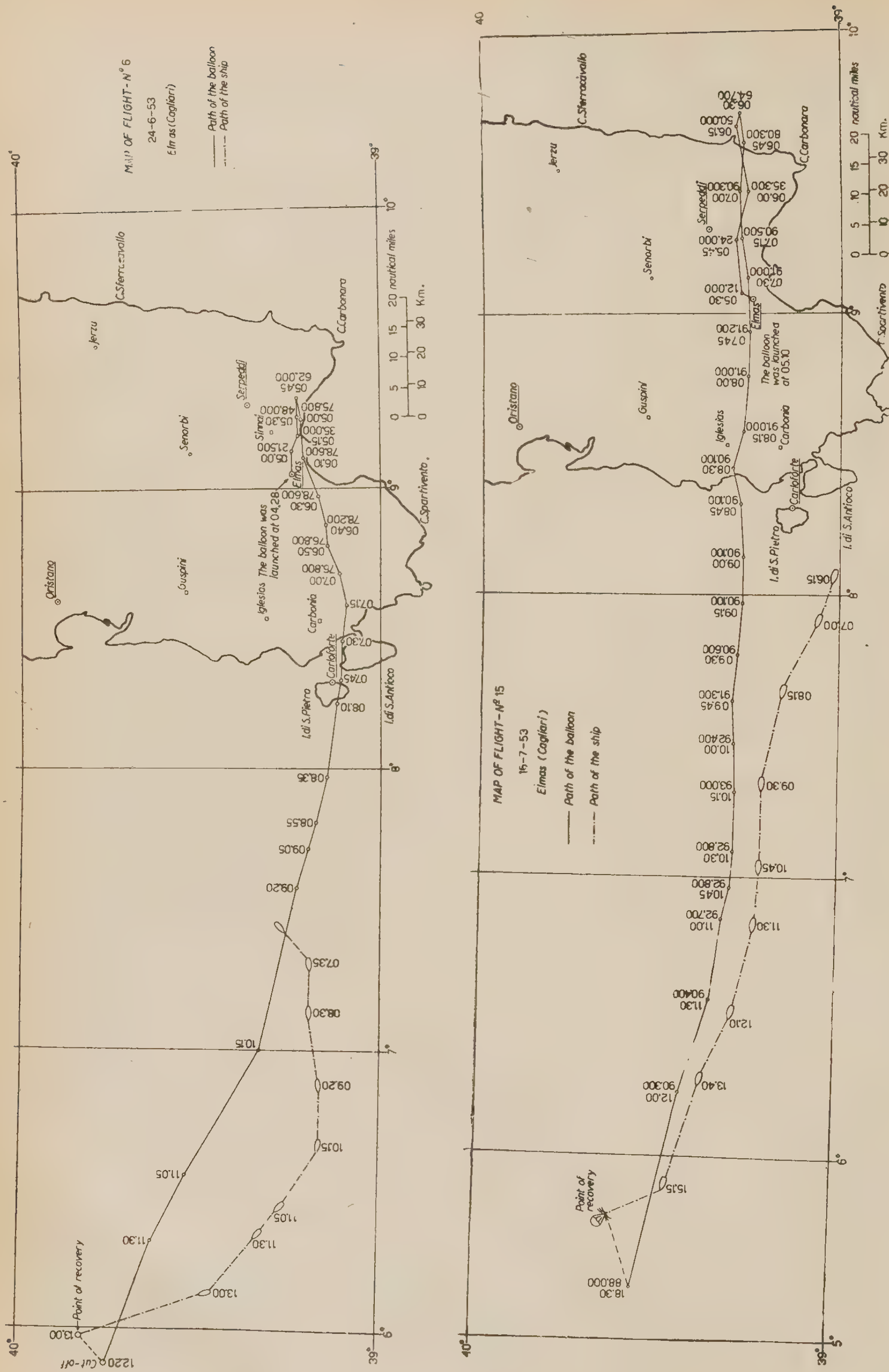

Fig. 5. – Maps of other flights.

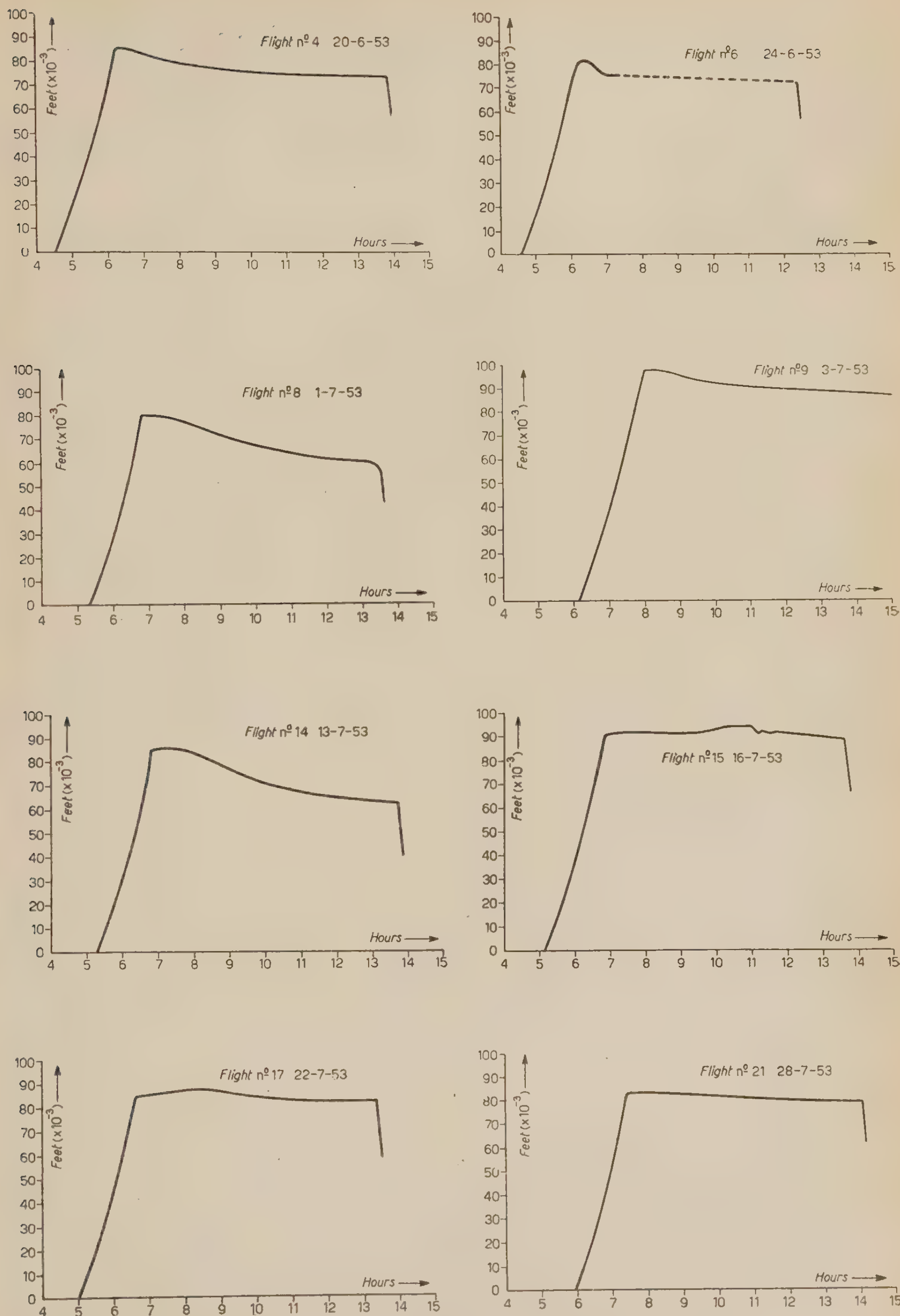

Fig. 6. – Altimetric profiles of the successful flights.

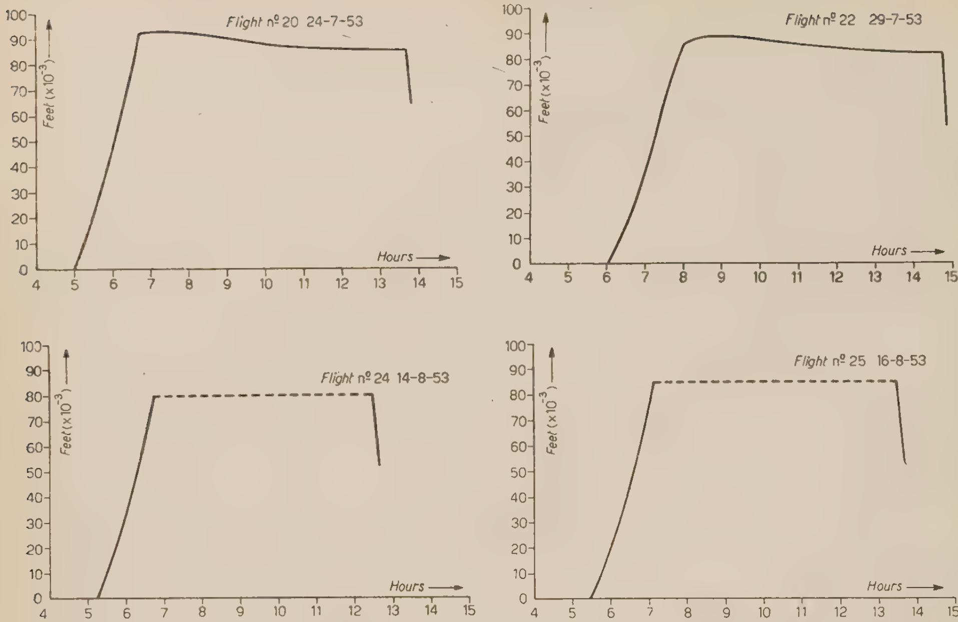

Fig. 7. – Altimetric profiles of the successful flights.

An attempt was made to bring down the envelope of the balloon at the time of release, as this would assist in the spotting of the equipment from the air and would ensure that the balloon did not stay afloat for a long period, gradually losing height due to diffusion of hydrogen.

The arrangement for this was as follows. The first clock cut-off severed the main cord and transfered the whole impulse of the falling equipment into the filling tube, about 10-12 m from the top of the balloon, which served as a rip panel; a further string reattached the parachute to the bottom of the balloon, to prevent the ripped envelope and the equipment being separated. The second clock was, in this case, set to operate about 90 minutes after the first, and arranged in such a way as to release the parachute completely from the balloon, in case the descent should be too slow.

The first test flight made in this way worked fairly satisfactorily, but due to the light load being carried, the hole made in the balloon was small, and the descent was not sufficiently rapid. The later flights rigged in this manner were those in which the parachute was not released, and in view of the importance of the fligths the technique was shelved. While rigging was at the time regarded as a possible cause of the release failures these were later shown to be probably due to the defects in the clocks, found at a later stage.

3·4. *Flight Records*. – Table III is a record of all the expedition's flights.

TABLE III. – *Flight record.*

Flight No.	Balloon type	Plates carried		Max. Altitude (ft.)	Cut-off Altitude (ft.)	Duration	REMARKS	Load (kg)
		Stripped	Glass					
1	32 (B)	1	—	5 000	—	— —	Burst, Plates recovered.	16.5
2	40 (B)	1, 2	—	81 000	74 000	$5^h\ 50^m$	Not recovered.	16.5
3	40 (B)	3, 4	1	81 000	—	—	Burst due to violent swinging.	19.5
4	40 (P)	5, 6	2	84 000	72 500	6 50	Recovered at sea.	22.5
5	50 (P)	7, 8	3	93 000	85 000	6 50	Not recovered.	25.0
6	40 (B)	9, 10	4	80 000	75 000	6 20	Recovered at sea.	23.5
7	24 (P)	trial flight		70 000	70 000	1 30	Radio cut-off functioned.	10.0
8	40 (P)	11		79 000	58 000	7 00	Recovered in Sardinia, envelope brought down.	21.0
9	50 (B)	12, 13	5	97 600	83 000 *	8 30 *	Clocks failed, recovered in Spain.	29.5
10	40 (P)	14, 15	6	87 000	80 000 *	8 00 *	Clocks failed, not recovered.	31.0
11	24 (P)	trial flight		70 000	—	—	Clocks failed, recovered in Sicily.	13.5
12	32 (B)	16	9	61 000	58 000	3 00	Failed to ascend normally, not recovered.	19.0
13	40 (P)	18, 19	7	—	—	—	Burst, plates recovered, radiosonde failed.	27.5
14	40 (P)	17, 20	8	85 000	62 500	7 10	Recovered at sea.	27.5
15	50 (P)	21, 22	10	93 000	87 000	6 40	Recovered at sea.	29.5
16	8 neoprene	23	—	64 000	—	—	Four balloons carried away.	—
17	40 (P)	26 ,29	12	86 000	81 000	6 50	Recovered at sea. Carried extra plates.	24.5
18	50 (P)	24, 25, 18	11	10 000	—	—	Burst after launch, plates reflown.	32.5
19	50 (P)	24, 25, 18	11	96 000	89 000	4 40	Not recovered; Balloon envelope found in Austria.	32.5
20	50 (B)	27, 28, 29	13	93 000	86 000	7 00	Recovered at sea. Carried extra plates.	33.0
21	40 (P)	30, 31	14	82 000	77 000	6 40	Recovered at sea.	26.5
22	50 (B)	32, 35	15	88 000	83 000	7 10	Recovered at sea. Carried extra plates.	35.5
23	8 neoprene	33	—	107 000	98 000	4 00	Not recovered, burst before cut-off.	14.0
24	40 (B)	36	17	80 000	75 000	5 30	Recovered, flown in Padua.	—
25	50 (B)	37	18, 19	86 000	77 000	6 30	Recovered, flown in Padua.	—

(B) Bristol Balloon. (P) Padua Balloon. * Last observations before signals lost.

The results can be conveniently summarised:

Trial flights (no plates)	2	
Balloon failures	6	(2 rubber)
Good flights not recovered	5	
Successful flights	12	
TOTAL	25	

It should be remarked that the loss of one rubber ballon was due to the premature bursting of some balloons, before the time set for the release of the parachute and equipment. The results suggest that due to uncertain performance, rubber or neoprene balloons are more suited to flights over a large land mass, where immediate recovery is not essential.

Twenty-two stacks were recovered from 37 flown, and 12 dozen plates from 19 flown. A total of about 9 litres of emulsion was successfully flown, recovered and developed. Two stacks were spoiled by irradiation in transit from Padua to Bristol, for processing.

4. – Abstract of the Proceedings of the Bern Meeting.

A conference was held at the Physics Institute, University of Bern, on October 1st and 2nd to arrange the distribution of the plates successfully flown, recovered and processed by the Expedition to Sardinia, 1953. All contributors were represented at this meeting.

It was reported that the expenses of the Expedition were estimated to exceed by about £ 3 000 the income of £ 17 000. As a result it was decided that a contribution of £ 1 000 i.e. one share, would entitle a laboratory to a complete stack of 40 emulsions, and that only half shares of £ 500 would be allowed as a subdivision. The stacks remaining after all contributors had made their selection would then be offered for sale, to reduce the financial deficit. The accounts would be finally balanced by sharing the remaining deficit amongst the contributors, in the proportion of their original share.

The half-share laboratories arranged themselves in pairs, in order to act as a single unit for the purpose of drawing lots, to establish the order of selection from the available stacks.

An assessment had already been made of the quality of each stack, account being taken of flight characteristics and processing, from which it appeared that the majority of the stacks were of uniform standards. A few stacks were outstanding either for their poor quality, or for being exceptionally good. After much discussion a method of drawing was adopted which made the final distribution most equitable.

Those large laboratories who had contributed £ 2 000, and were entitled to two stacks, took part in a preliminary draw, for one stack each, and selected what they considered to be the better stacks. After the one share laboratories had drawn lots and chosen their stacks, the two share contributors returned in the reverse order to select their second stack, from the few remaining poorer stacks.

An opportunity was given to all contributors before the draw, to increase their share to £ 2 000, in order to take part in the preliminary draw between two share contributors only. The following laboratories took advantage of the offer: Turin £ 2000, Milan £ 1000, Genoa £ 500, Brussells £ 500.

The final order of selection and the stacks chosen, is listed in Table IV.

TABLE IV.

Order of the Draw	Laboratory	Stack chosen	Order of the Draw	Laboratory	Stack chosen
1	Milan-Genoa-Brussels	31	10	Catania-Sydney . . .	12
2	Turin	19	11	Göttingen-Dublin . .	30
3	Bristol	35	12	Lund	32
4	Rome	21	13	Padua	6
5	Padua	27	14	Rome	29
6	Paris	22	15	Bristol	11
7	Bern	13	16	Turin	10
8	Copenhagen-Oslo . .	17	17	Milan-Genoa-Brussels	9
9	Göttingen	28			

Three half stacks have been sold:

Trondheim	5	(plates 1-20)
Paris (École Normale) . .	36	(plates 21-40)
Warsaw	20	(plates 21-40)

and ten packets of the glass backed plates.

5. – Financial Account of the Expedition.

Following some discussion at the Bern meeting, a method was established of assessing the total contribution of the laboratories actively engaged with preparations for the expedition. It was agreed that the equipment prepared for the expedition should be placed in two categories:

i) Expendable; e.g. radio-transmitters, balloons, clock-releases.
ii) Non-expendable: such as plant for balloon manufacture, or plate processing, radio receivers, launching platform.

For category i) apparatus, all materials and labour should be charged to the expedition, while only a one-third part of category, ii) materials and labour should be a charge on the expedition account. A nominal charge was also made for the work of processing. The laboratories were then invited to send lists of their expenses, prepared in the above manner, either to Rome or to Bristol.

The deficit of the expedition consisted chiefly of a debt of several thousand pounds to Ilford Ltd., the greater part of which had been paid by loans to the expedition from Bristol University, and from Rome University. In February, 1954, it appeared that all the saleable plates had been disposed of, and in order to repay the loans and discharge all the debts, the collaborating laboratories were asked to contribute an extra 10% of their shares. All payments of this levy have not yet been received, so it is not yet possible to close the accounts of the expedition and issue a detailed balance sheet.

The following summary gives some indication of the relative proportion of the various expenses of the expedition.

Table V. – *Summary of Income and Expenditure.*

	£	s	d	£	s	d	£	s	d
Total income: 17 shares of £ 1 000 each							17 000	0	0
Expenses in Laboratories:									
Bern	425	8	0						
Bristol	4 557	12	0						
Geneva	213	2	0						
Göttingen	379	19	0						
Lund	55	0	0						
Milan	634	18	0						
Padua	2 990	16	0						
Rome	2 107	0	0						
Other Laboratoires	—	16	0						
	11 364	11	0	11 364	11	0			
Nuclear Research Emulsions				3 772	0	0			
Hydrogen				1 063	0	0			
Paid from account in Rome				1 375	0	0			
Paid from account in Cagliari				2 530	0	0			
				20 104	11	0			
10% of all original contributions							1 700	0	0
Funds expected from sale of plates etc.							1 970	0	0
Total							20 670	0	0

6. – Acknowledgements.

It is with great pleasure that we, on behalf of the Expedition to Sardinia, 1953, acknowledge the cooperation and invaluable assistance of the following organisations and persons: the Stato Maggiore of the Italian Defence Ministry; the Comando Militare Marittimo di Sardegna, the Commander and the Crew of the ship « Corvetta Pomona » of the Italian Navy; the Stato Maggiore, the Segretariato Generale, the Ispettorato Telecomunicazioni e Assistenza Voli, the Comando Aeronautico III ZAT, the Comando Aeronautico Sardegna, the Centro Soccorso Elmas, the Comando Aeroporto Elmas, of the Italian Air Force; the Comando Generale of the Guardie di Finanza; the British Department of Scientific and Industrial Research, the Consiglio Nazionale delle Ricerche.

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